6. Land Use, Land-Use Change, and Forestry

This chapter provides an assessment of the net greenhouse gas flux resulting from the uses and changes in land types and forests in the United States.[1] The Intergovernmental Panel on Climate Change *2006 Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) recommends reporting fluxes according to changes within and conversions between certain land-use types termed: Forest Land, Cropland, Grassland, Settlements, Wetlands (as well as Other Land). The greenhouse gas flux from *Forest Land Remaining Forest Land* is reported using estimates of changes in forest carbon (C) stocks, non-carbon dioxide (non-CO_2) emissions from forest fires, and the application of synthetic fertilizers to forest soils. The greenhouse gas flux from agricultural lands (i.e., Cropland and Grassland) that is reported in this chapter includes changes in organic C stocks in mineral and organic soils due to land use and management, and emissions of CO_2 due to the application of crushed limestone and dolomite to managed land (i.e., soil liming) and urea fertilization. Fluxes are reported for four agricultural land use/land-use change categories: *Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland*, and *Land Converted to Grassland*. Fluxes resulting from *Settlements Remaining Settlements* include those from urban trees and soil fertilization. Landfilled yard trimmings and food scraps are accounted for separately under *Other*.

The estimates in this chapter, with the exception of CO_2 removals from harvested wood products and urban trees, and CO_2 emissions from liming and urea fertilization, are based on activity data collected at multiple-year intervals, which are in the form of forest, land use, and municipal solid waste surveys. Carbon dioxide fluxes from forest C stocks (except the harvested wood product components) and from agricultural soils (except the liming component) are calculated on an average annual basis from data collected in intervals ranging from one to 10 years. The resulting annual averages are applied to years between surveys. Calculations of non-CO_2 emissions from forest fires are based on forest CO_2 flux data. For the landfilled yard trimmings and food scraps source, historical annual solid waste survey data were interpolated where annual data were missing so that annual storage estimates could be derived. This flux has been applied to the entire time series, and periodic U.S. census data on changes in urban area have been used to develop annual estimates of CO_2 flux.

Land use, land-use change, and forestry activities in 2013 resulted in a C sequestration (i.e., total sinks) of 881.7 MMT CO_2 Eq.[2] (240.5 MMT C).[3] This represents an offset of approximately 13.2 percent of total (i.e., gross)

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[1] The term "flux" is used to describe the net emissions of greenhouse gases to the atmosphere accounting for both the emissions of CO_2 to and the removals of CO_2 from the atmosphere. Removal of CO_2 from the atmosphere is also referred to as "carbon sequestration".

[2] Following the revised reporting requirements under the UNFCCC, this Inventory report presents CO_2 equivalent values based on the *IPCC Fourth Assessment Report* (AR4) GWP values. See the Introduction chapter for more information.

[3] The total sinks value includes the positive C sequestration reported for *Forest Land Remaining Forest Land, Cropland Remaining Cropland, Land Converted to Grassland, Settlements Remaining Settlements,* and *Other Land* plus the loss in C sequestration reported for *Land Converted to Cropland* and *Grassland Remaining Grassland*.

greenhouse gas emissions in 2013. Emissions from land use, land-use change, and forestry activities in 2013 represent 0.3 percent of total greenhouse gas emissions.[4]

Total land use, land-use change, and forestry C sequestration increased by approximately 13.6 percent between 1990 and 2013. This increase was primarily due to an increase in the rate of net C accumulation in forest C stocks.[5] Net C accumulation in *Forest Land Remaining Forest Land, Land Converted to Grassland,* and *Settlements Remaining Settlements* increased, while net C accumulation in *Cropland Remaining Cropland, Grassland Remaining Grassland,* and *Landfilled Yard Trimmings and Food Scraps* slowed over this period. Emissions from *Land Converted to Cropland* and *Wetlands Remaining Wetlands* decreased. Emissions and removals for Land Use, Land-Use Change, and Forestry are summarized in Table 6-1 by land-use and source category.

Table 6-1: Emissions and Removals (Flux) from Land Use, Land-Use Change, and Forestry by Land-Use Change Category (MMT CO_2 Eq.)

Land-Use/Source Category	1990	2005	2009	2010	2011	2012	2013
Forest Land Remaining Forest Land	**(635.2)**	**(792.9)**	**(754.7)**	**(757.1)**	**(749.2)**	**(746.7)**	**(765.5)**
Changes in Forest Carbon Stock[a]	(639.4)	(807.1)	(764.9)	(765.4)	(773.8)	(773.1)	(775.7)
Forest Fires	4.2	13.8	9.7	7.9	24.2	26.0	9.7
Forest Soils[b]	0.1	0.5	0.5	0.5	0.5	0.5	0.5
Cropland Remaining Cropland	**(58.1)**	**(20.2)**	**(20.2)**	**(17.3)**	**(17.8)**	**(15.0)**	**(13.5)**
Changes in Agricultural Soil Carbon Stock	(65.2)	(28.0)	(27.5)	(25.9)	(25.8)	(25.0)	(23.4)
Liming of Agricultural Soils	4.7	4.3	3.7	4.8	3.9	5.8	5.9
Urea Fertilization	2.4	3.5	3.6	3.8	4.1	4.2	4.0
Land Converted to Cropland	**24.5**	**19.8**	**16.2**	**16.2**	**16.2**	**16.1**	**16.1**
Changes in Agricultural Soil Carbon Stock	24.5	19.8	16.2	16.2	16.2	16.1	16.1
Grassland Remaining Grassland	**(1.9)**	**4.2**	**11.7**	**11.7**	**11.7**	**11.5**	**12.1**
Changes in Agricultural Soil Carbon Stock	(1.9)	4.2	11.7	11.7	11.7	11.5	12.1
Land Converted to Grassland	**(7.4)**	**(9.0)**	**(8.9)**	**(8.9)**	**(8.9)**	**(8.8)**	**(8.8)**
Changes in Agricultural Soil Carbon Stock	(7.4)	(9.0)	(8.9)	(8.9)	(8.9)	(8.8)	(8.8)
Settlements Remaining Settlements	**(59.0)**	**(78.2)**	**(82.8)**	**(83.8)**	**(84.8)**	**(85.8)**	**(87.1)**
Changes in Urban Tree Carbon Stock[c]	(60.4)	(80.5)	(85.0)	(86.1)	(87.3)	(88.4)	(89.5)
Settlement Soils[d]	1.4	2.3	2.2	2.4	2.5	2.5	2.4
Wetlands Remaining Wetlands	**1.1**	**1.1**	**1.0**	**1.0**	**0.9**	**0.8**	**0.8**
Peatlands Remaining Peatlands	1.1	1.1	1.0	1.0	0.9	0.8	0.8
Other	**(26.0)**	**(11.4)**	**(12.5)**	**(13.2)**	**(13.2)**	**(12.8)**	**(12.6)**
Landfilled Yard Trimmings and Food Scraps	(26.0)	(11.4)	(12.5)	(13.2)	(13.2)	(12.8)	(12.6)
Total Flux[e]	**(762.1)**	**(886.4)**	**(850.2)**	**(851.3)**	**(844.9)**	**(840.6)**	**(858.5)**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

[a] Estimates include C stock changes on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

[b] Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land,* and *Land Converted to Forest Land,* but not from land-use conversion.

[c] Estimates include C stock changes on both *Settlements Remaining Settlements* and *Land Converted to Settlements*.

[d] Estimates include emissions from N fertilizer additions on both *Settlements Remaining Settlements,* and *Land Converted to Settlements*, but not from land-use conversion.

[e] "Total Flux" is defined as the sum of positive emissions (i.e., sources) of greenhouse gases to the atmosphere plus removals of CO_2 (i.e., sinks or negative emissions) from the atmosphere.

Note: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

CO_2 removals are presented in Table 6-2 along with CO_2, CH_4, and N_2O emissions from Land use, Land-Use Change, and Forestry source categories. Liming of agricultural soils and urea fertilization in 2013 resulted in CO_2 emissions of 9.9 MMT CO_2 Eq. (9,936 kt). Lands undergoing peat extraction (i.e., *Peatlands Remaining Peatlands*)

[4] The emissions value includes the CO_2, CH_4, and N_2O emissions reported for *Forest Fires, Forest Soils, Liming of Agricultural Soils, Urea Fertilization, Settlement Soils,* and *Peatlands Remaining Peatlands*.

[5] Carbon sequestration estimates are net figures. The C stock in a given pool fluctuates due to both gains and losses. When losses exceed gains, the C stock decreases, and the pool acts as a source. When gains exceed losses, the C stock increases, and the pool acts as a sink; also referred to as net C sequestration or removal.

resulted in CO_2 emissions of 0.8 MMT CO_2 Eq. (770 kt), methane (CH_4) emissions of less than 0.05 MMT CO_2 Eq., and nitrous oxide (N_2O) emissions of less than 0.05 MMT CO_2 Eq. The application of synthetic fertilizers to forest soils in 2013 resulted in N_2O emissions of 0.5 MMT CO_2 Eq. (2 kt). N_2O emissions from fertilizer application to forest soils have increased by 455 percent since 1990, but still account for a relatively small portion of overall emissions. Additionally, N_2O emissions from fertilizer application to settlement soils in 2013 accounted for 2.4 MMT CO_2 Eq. (8 kt). This represents an increase of 77 percent since 1990. Forest fires in 2013 resulted in CH_4 emissions of 5.8 MMT CO_2 Eq. (233 kt), and in N_2O emissions of 3.8 MMT CO_2 Eq. (13 kt). Emissions and removals for Land Use, Land-Use Change, and Forestry are shown in Table 6-2 and Table 6-3.

Table 6-2: Emissions and Removals (Flux) from Land Use, Land-Use Change, and Forestry (MMT CO_2 Eq.)

Gas/Land-Use Category	1990		2005		2009	2010	2011	2012	2013
CO_2	**(767.7)**		**(903.0)**		**(862.6)**	**(862.0)**	**(872.1)**	**(869.6)**	**(871.0)**
Forest Land Remaining Forest Land: Changes in Forest Carbon Stock[a]	(639.4)		(807.1)		(764.9)	(765.4)	(773.8)	(773.1)	(775.7)
Cropland Remaining Cropland: Changes in Agricultural Soil Carbon Stock	(65.2)		(28.0)		(27.5)	(25.9)	(25.8)	(25.0)	(23.4)
Cropland Remaining Cropland: Liming of Agricultural Soils	4.7		4.3		3.7	4.8	3.9	5.8	5.9
Cropland Remaining Cropland: Urea Fertilization	2.4		3.5		3.6	3.8	4.1	4.2	4.0
Land Converted to Cropland	24.5		19.8		16.2	16.2	16.2	16.1	16.1
Grassland Remaining Grassland	(1.9)		4.2		11.7	11.7	11.7	11.5	12.1
Land Converted to Grassland	(7.4)		(9.0)		(8.9)	(8.9)	(8.9)	(8.8)	(8.8)
Settlements Remaining Settlements: Changes in Urban Tree Carbon Stock[b]	(60.4)		(80.5)		(85.0)	(86.1)	(87.3)	(88.4)	(89.5)
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	1.1		1.1		1.0	1.0	0.9	0.8	0.8
Other: Landfilled Yard Trimmings and Food Scraps	(26.0)		(11.4)		(12.5)	(13.2)	(13.2)	(12.8)	(12.6)
CH_4	**2.5**		**8.3**		**5.8**	**4.8**	**14.6**	**15.7**	**5.8**
Forest Land Remaining Forest Land: Forest Fires	2.5		8.3		5.8	4.7	14.6	15.7	5.8
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+		+		+	+	+	+	+
N_2O	**3.1**		**8.3**		**6.5**	**6.0**	**12.6**	**13.3**	**6.7**
Forest Land Remaining Forest Land: Forest Fires	1.7		5.5		3.8	3.1	9.6	10.3	3.8
Forest Land Remaining Forest Land: Forest Soils[c]	0.1		0.5		0.5	0.5	0.5	0.5	0.5
Settlements Remaining Settlements: Settlement Soils[d]	1.4		2.3		2.2	2.4	2.5	2.5	2.4
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+		+		+	+	+	+	+
Total Flux[e]	**(762.1)**		**(886.4)**		**(850.2)**	**(851.3)**	**(844.9)**	**(840.6)**	**(858.5)**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
+ Less than 0.05 MMT CO_2 Eq.
[a] Estimates include C stock changes on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.
[b] Estimates include C stock changes on both *Settlements Remaining Settlements* and *Land Converted to Settlements*.
[c] Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land*, and *Land Converted to Forest Land*, but not from land-use conversion.
[d] Estimates include emissions from N fertilizer additions on both *Settlements Remaining Settlements*, and *Land Converted to Settlements*, but not from land-use conversion
[e] "Total Flux" is defined as the sum of positive emissions (i.e., sources) of greenhouse gases to the atmosphere plus removals of CO_2 (i.e., sinks or negative emissions) from the atmosphere.
Note: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Table 6-3: Emissions and Removals (Flux) from Land Use, Land-Use Change, and Forestry (kt)

Gas/Land-Use Category	1990	2005	2009	2010	2011	2012	2013
CO_2	**(767,697)**	**(902,974)**	**(862,631)**	**(862,025)**	**(872,103)**	**(869,580)**	**(871,026)**
Forest Land Remaining Forest Land: Changes in Forest Carbon Stock[a]	(639,432)	(807,075)	(764,871)	(765,410)	(773,843)	(773,110)	(775,677)
Cropland Remaining Cropland: Changes in Agricultural Soil Carbon Stock	(65,196)	(28,035)	(27,473)	(25,867)	(25,752)	(24,990)	(23,432)
Cropland Remaining Cropland: Liming of Agricultural Soils	4,667	4,349	3,669	4,784	3,871	5,776	5,925
Cropland Remaining Cropland: Urea Fertilization	2,417	3,504	3,555	3,778	4,099	4,225	4,011
Land Converted to Cropland	24,498	19,830	16,194	16,194	16,194	16,095	16,125
Grassland Remaining Grassland	(1,913)	4,230	11,704	11,694	11,680	11,532	12,083
Land Converted to Grassland	(7,410)	(8,995)	(8,917)	(8,894)	(8,871)	(8,783)	(8,757)
Settlements Remaining Settlements: Changes in Urban Tree Carbon Stock[b]	(60,408)	(80,523)	(85,008)	(86,129)	(87,250)	(88,372)	(89,493)
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	1,055	1,101	1,024	1,022	926	812	770
Other: Landfilled Yard Trimmings and Food Scraps	(25,975)	(11,360)	(12,508)	(13,197)	(13,156)	(12,766)	(12,581)
CH_4	**101**	**332**	**234**	**190**	**584**	**627**	**233**
Forest Land Remaining Forest Land: Forest Fires	101	332	233	190	584	626	233
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+
N_2O	**10**	**28**	**22**	**20**	**42**	**45**	**23**
Forest Land Remaining Forest Land: Forest Fires	6	18	13	11	32	35	13
Forest Land Remaining Forest Land: Forest Soils[c]	+	2	2	2	2	2	2
Settlements Remaining Settlements: Settlement Soils[d]	5	8	8	8	8	8	8
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+

+ Emissions are less than 0.5 kt

[a] Estimates include C stock changes on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

[b] Estimates include C stock changes on both *Settlements Remaining Settlements* and *Land Converted to Settlements*.

[c] Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land*, and *Land Converted to Forest Land*, but not from land-use conversion.

[d] Estimates include emissions from N fertilizer additions on both *Settlements Remaining Settlements*, and *Land Converted to Settlements*, but not from land-use conversion.

Note: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Box 6-1: Methodological Approach for Estimating and Reporting U.S. Emissions and Sinks

In following the UNFCCC requirement under Article 4.1 to develop and submit national greenhouse gas emissions inventories, the emissions and sinks presented in this report are organized by source and sink categories and calculated using internationally-accepted methods provided by the Intergovernmental Panel on Climate Change

(IPCC).[6] Additionally, the calculated emissions and sinks in a given year for the United States are presented in a common manner in line with the UNFCCC reporting guidelines for the reporting of inventories under this international agreement.[7] The use of consistent methods to calculate emissions and sinks by all nations providing their inventories to the UNFCCC ensures that these reports are comparable. In this regard, U.S. emissions and sinks reported in this Inventory report are comparable to emissions and sinks reported by other countries. The manner that emissions and sinks are provided in this Inventory is one of many ways U.S. emissions and sinks could be examined; this Inventory report presents emissions and sinks in a common format consistent with how countries are to report inventories under the UNFCCC. The report itself follows this standardized format, and provides an explanation of the IPCC methods used to calculate emissions and sinks, and the manner in which those calculations are conducted.

6.1 Representation of the U.S. Land Base

A national land-use categorization system that is consistent and complete, both temporally and spatially, is needed in order to assess land use and land-use change status and the associated greenhouse gas (GHG) fluxes over the Inventory time series. This system should be consistent with IPCC (2006), such that all countries reporting on national GHG fluxes to the UNFCCC should: (1) Describe the methods and definitions used to determine areas of managed and unmanaged lands in the country, (2) describe and apply a consistent set of definitions for land-use categories over the entire national land base and time series (i.e., such that increases in the land areas within particular land-use categories are balanced by decreases in the land areas of other categories unless the national land base is changing), and (3) account for GHG fluxes on all managed lands. The IPCC (2006, Vol. IV, Chapter 1) considers all anthropogenic GHG emissions and removals associated with land use and management to occur on managed land, and all emissions and removals on managed land should be reported based on this guidance (see IPCC 2010 for further discussion). Consequently, managed land serves as a proxy for anthropogenic emissions and removals. This proxy is intended to provide a practical framework for conducting an inventory, even though some of the GHG emissions and removals on managed land are influenced by natural processes that may or may not be interacting with the anthropogenic drivers. Guidelines for factoring out natural emissions and removals may be developed in the future, but currently the managed land proxy is considered the most practical approach for conducting an inventory in this sector (IPCC 2010). The implementation of such a system helps to ensure that estimates of GHG fluxes are as accurate as possible, and does allow for potentially subjective decisions in regards to subdividing natural and anthropogenic driven emissions. This section of the Inventory has been developed in order to comply with this guidance.

Three databases are used to track land management in the United States and are used as the basis to classify U.S. land area into the thirty-six IPCC land-use and land-use change categories (Table 6-5) (IPCC 2006). The primary databases are the U.S. Department of Agriculture (USDA) National Resources Inventory (NRI)[8] and the USDA Forest Service (USFS) Forest Inventory and Analysis (FIA)[9] Database. The Multi-Resolution Land Characteristics Consortium (MRLC) National Land Cover Dataset (NLCD)[10] is also used to identify land uses in regions that were not included in the NRI or FIA.

The total land area included in the U.S. Inventory is 936 million hectares across the 50 states.[11] Approximately 890 million hectares of this land base is considered managed, which has not changed by much over the time series of the

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[6] See <http://www.ipcc-nggip.iges.or.jp/public/index.html>.

[7] See <http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf>.

[8] NRI data is available at <http://www.nrcs.usda.gov/wps/portal/nrcs/site/national/home>.

[9] FIA data is available at <http://www.fia.fs.fed.us/tools-data/default.asp>.

[10] NLCD data is available at <http://www.mrlc.gov/> and MRLC is a consortium of several U.S. government agencies.

[11] The current land representation does not include areas from U.S. territories, but there are planned improvements to include these regions in future reports.

Inventory (Table 6-5). In 2013, the United States had a total of 293 million hectares of managed Forest Land (1.3 percent increase since 1990), 159 million hectares of Cropland (6.6 percent decrease since 1990), 321 million hectares of managed Grassland (1.1 percent decrease since 1990), 43 million hectares of managed Wetlands (3 percent decrease since 1990), 51 million hectares of Settlements (31 percent increase since 1990), and 24 million hectares of managed Other Land (Table 6-5). Wetlands are not differentiated between managed and unmanaged, and are reported solely as managed. Some wetlands would be considered unmanaged, and a future planned improvement will include a differentiation between managed and unmanaged wetlands using guidance in the *2013 Supplement to the 2006 Guidelines for National Greenhouse Gas Inventories: Wetlands*. In addition, C stock changes are not currently estimated for the entire land base, which leads to discrepancies between the managed land area data presented here and in the subsequent sections of the Inventory (e.g., Grassland Remaining Grassland).[12,13] Planned improvements are under development to account for C stock changes on all managed land (e.g., federal grasslands) and ensure consistency between the total area of managed land in the land-representation description and the remainder of the Inventory.

Dominant land uses vary by region, largely due to climate patterns, soil types, geology, proximity to coastal regions, and historical settlement patterns, although all land uses occur within each of the 50 states (Table 6-4). Forest Land tends to be more common in the eastern states, mountainous regions of the western United States, and Alaska. Cropland is concentrated in the mid-continent region of the United States, and Grassland is more common in the western United States and Alaska. Wetlands are fairly ubiquitous throughout the United States, though they are more common in the upper Midwest and eastern portions of the country. Settlements are more concentrated along the coastal margins and in the eastern states.

Table 6-4: Managed and Unmanaged Land Area by Land-Use Categories for All 50 States (Thousands of Hectares)

Land-Use Categories	1990	2005	2009	2010	2011	2012	2013
Managed Lands	**890,018**	**890,016**	**890,016**	**890,017**	**890,017**	**890,017**	**890,017**
Forest Land	288,964	291,213	292,263	292,399	292,516	292,634	292,751
Croplands	170,448	160,107	159,248	159,243	159,238	159,234	159,230
Grasslands	324,327	321,360	320,666	320,657	320,655	320,652	320,648
Settlements	38,602	49,676	50,628	50,624	50,621	50,617	50,614
Wetlands	44,453	44,060	43,441	43,330	43,228	43,126	43,025
Other Land	23,225	23,600	23,770	23,765	23,759	23,754	23,748
Unmanaged Lands	**46,212**	**46,214**	**46,214**	**46,213**	**46,213**	**46,214**	**46,214**
Forest Land	9,634	9,634	9,634	9,634	9,634	9,634	9,634
Croplands	0	0	0	0	0	0	0
Grasslands	25,782	25,782	25,782	25,782	25,782	25,782	25,782
Settlements	0	0	0	0	0	0	0
Wetlands	0	0	0	0	0	0	0
Other Land	10,796	10,798	10,798	10,797	10,797	10,797	10,797
Total Land Areas	**936,230**	**936,230**	**936,230**	**936,230**	**936,230**	**936,230**	**936,230**
Forest Land	298,598	300,848	301,898	302,033	302,151	302,268	302,386
Croplands	170,448	160,107	159,248	159,243	159,238	159,234	159,230
Grasslands	350,109	347,142	346,448	346,439	346,437	346,434	346,430
Settlements	38,602	49,676	50,628	50,624	50,621	50,617	50,614
Wetlands	44,453	44,060	43,441	43,330	43,228	43,126	43,025
Other Land	34,021	34,397	34,568	34,562	34,556	34,551	34,545

[12] C stock changes are not estimated for approximately 75 million hectares of Grassland Remaining Grassland. See specific land-use sections for further discussion on gaps in the inventory of C stock changes, and discussion about planned improvements to address the gaps in the near future.

[13] These "managed area" discrepancies also occur in the Common Reporting Format (CRF) tables submitted to the UNFCCC.

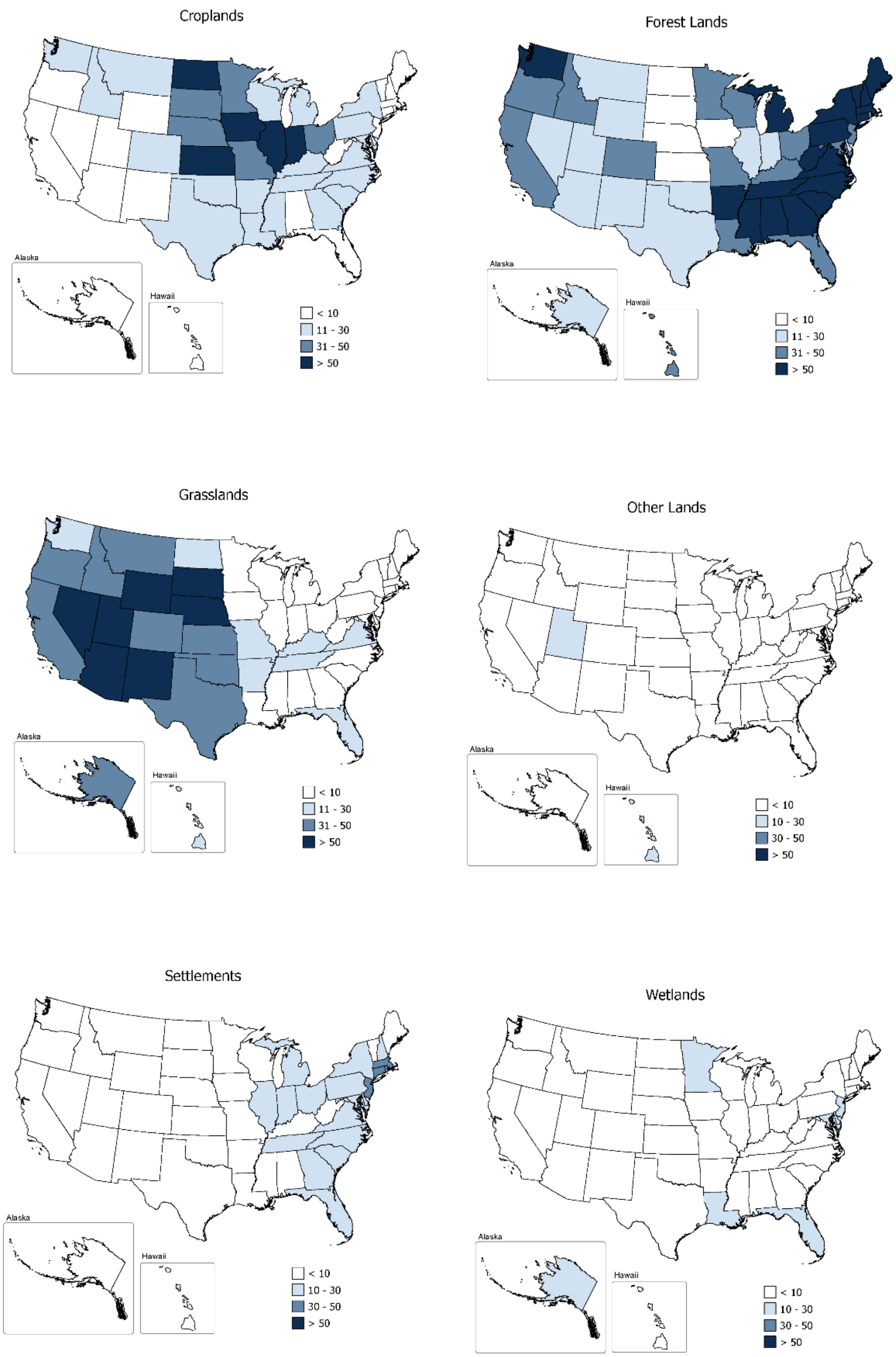
Table 6-5: Land Use and Land-Use Change for the U.S. Managed Land Base for All 50 States (Thousands of Hectares)

Land-Use & Land-Use Change Categories[a]	1990	2005	2009	2010	2011	2012	2013
Total Forest Land	**288,964**	**291,213**	**292,263**	**292,399**	**292,516**	**292,634**	**292,751**
FF	283,860	278,979	280,844	280,977	281,092	281,207	281,322
CF	1,119	2,656	2,449	2,450	2,450	2,450	2,450
GF	3,434	7,805	7,279	7,280	7,280	7,281	7,281
WF	64	250	257	257	258	258	259
SF	103	362	376	376	376	377	377
OF	383	1,161	1,057	1,059	1,060	1,062	1,063
Total Cropland	**170,448**	**160,107**	**159,248**	**159,243**	**159,238**	**159,234**	**159,230**
CC	154,527	143,050	143,933	143,928	143,924	143,920	143,916
FC	1,148	688	577	576	576	576	576
GC	13,988	15,216	13,655	13,655	13,655	13,655	13,655
WC	161	199	176	176	176	175	175
SC	438	692	672	672	672	672	672
OC	185	262	236	236	236	236	236
Total Grassland	**324,327**	**321,360**	**320,666**	**320,657**	**320,655**	**320,652**	**320,648**
GG	313,914	301,823	302,566	302,594	302,627	302,660	302,692
FG	1,615	3,022	2,757	2,755	2,753	2,752	2,750
CG	8,099	14,986	13,912	13,878	13,844	13,810	13,776
WG	238	409	330	329	329	329	329
SG	112	274	267	267	267	267	267
OG	350	846	834	834	834	834	834
Total Wetlands	**44,453**	**44,060**	**43,441**	**43,330**	**43,228**	**43,126**	**43,025**
WW	43,802	42,545	42,002	41,892	41,792	41,691	41,592
FW	143	397	382	381	380	379	378
CW	132	365	345	345	344	344	344
GW	343	698	664	664	664	664	664
SW	0	10	10	10	10	10	10
OW	32	44	39	39	38	38	38
Total Settlements	**38,602**	**49,676**	**50,628**	**50,624**	**50,621**	**50,617**	**50,614**
SS	34,060	35,269	36,340	36,337	36,334	36,330	36,328
FS	1,787	6,112	6,090	6,090	6,090	6,090	6,089
CS	1,344	3,633	3,526	3,526	3,526	3,526	3,526
GS	1,353	4,433	4,439	4,439	4,439	4,439	4,439
WS	3	31	30	30	30	30	30
OS	55	200	202	202	202	202	202
Total Other Land	**23,225**	**23,600**	**23,770**	**23,765**	**23,759**	**23,754**	**23,748**
OO	22,175	21,372	21,470	21,466	21,460	21,455	21,450
FO	182	538	569	569	569	570	570
CO	345	645	703	703	703	703	703
GO	454	903	902	902	902	901	901
WO	67	121	104	104	104	104	104
SO	2	21	20	20	20	20	20
Grand Total	**890,018**	**890,016**	**890,016**	**890,017**	**890,017**	**890,017**	**890,017**

[a] The abbreviations are "F" for Forest Land, "C" for Cropland, "G" for Grassland, "W" for Wetlands, "S" for Settlements, and "O" for Other Lands. Lands remaining in the same land-use category are identified with the land-use abbreviation given twice (e.g., "FF" is Forest Land Remaining Forest Land), and land-use change categories are identified with the previous land use abbreviation followed by the new land-use abbreviation (e.g., "CF" is Cropland Converted to Forest Land).

Note: All land areas reported in this table are considered managed. A planned improvement is underway to deal with an exception for wetlands, which based on the definitions for the current U.S. Land Representation Assessment includes both managed and unmanaged lands. U.S. Territories have not been classified into land uses and are not included in the U.S. Land Representation Assessment. See the Planned Improvements section for discussion on plans to include territories in future inventories. In addition, C stock changes are not currently estimated for the entire land base, which leads to discrepancies between the managed land area data presented here and in the subsequent sections of the Inventory.

Figure 6-1: Percent of Total Land Area for Each State in the General Land-Use Categories for 2013



Methodology

IPCC Approaches for Representing Land Areas

IPCC (2006) describes three approaches for representing land areas. Approach 1 provides data on the total area for each individual land-use category, but does not provide detailed information on changes of area between categories and is not spatially explicit other than at the national or regional level. With Approach 1, total net conversions between categories can be detected, but not the individual changes (i.e., additions and/or losses) between the land-use categories that led to those net changes. Approach 2 introduces tracking of individual land-use changes between the categories (e.g., Forest Land to Cropland, Cropland to Forest Land, and Grassland to Cropland), using survey samples or other forms of data, but does not provide location data on all parcels of land. Approach 3 extends Approach 2 by providing location data on all parcels of land, such as maps, along with the land-use history. The three approaches are not presented as hierarchical tiers and are not mutually exclusive.

According to IPCC (2006), the approach or mix of approaches selected by an inventory agency should reflect calculation needs and national circumstances. For this analysis, the NRI, FIA, and the NLCD have been combined to provide a complete representation of land use for managed lands. These data sources are described in more detail later in this section. NRI and FIA are Approach 2 data sources that do not provide spatially-explicit representations of land use and land-use conversions, even though land use and land-use conversions are tracked explicitly at the survey locations. NRI and FIA data can only be aggregated and used to develop a land-use conversion matrix for a political or ecologically-defined region. NLCD is a spatially-explicit time series of land-cover data that is used to inform the classification of land use, and is therefore Approach 3 data. Lands are treated as remaining in the same category (e.g., Cropland Remaining Cropland) if a land-use change has not occurred in the last 20 years. Otherwise, the land is classified in a land-use change category based on the current use and most recent use before conversion to the current use (e.g., Cropland Converted to Forest Land).

Definitions of Land Use in the United States

Managed and Unmanaged Land

The United States definition of managed land is similar to the basic IPCC (2006) definition of managed land, but with some additional elaboration to reflect national circumstances. Based on the following definitions, most lands in the United States are classified as managed:

- *Managed Land*: Land is considered managed if direct human intervention has influenced its condition. Direct intervention occurs mostly in areas accessible to human activity and includes altering or maintaining the condition of the land to produce commercial or non-commercial products or services; to serve as transportation corridors or locations for buildings, landfills, or other developed areas for commercial or non-commercial purposes; to extract resources or facilitate acquisition of resources; or to provide social functions for personal, community, or societal objectives where these areas are readily accessible to society.[14]
- *Unmanaged Land*: All other land is considered unmanaged. Unmanaged land is largely comprised of areas inaccessible to society due to the remoteness of the locations. Though these lands may be influenced

[14] Wetlands are an exception to this general definition, because these lands, as specified by IPCC (2006), are only considered managed if they are created through human activity, such as dam construction, or the water level is artificially altered by human activity. Distinguishing between managed and unmanaged wetlands is difficult due to limited data availability. Wetlands are not characterized by use within the NRI. Therefore, unless wetlands are managed for cropland or grassland, it is not possible to know if they are artificially created or if the water table is managed based on the use of NRI data. As a result, all wetlands are reported as managed. See the Planned Improvements section of the Inventory for work being done to refine the Wetland area estimates.

indirectly by human actions such as atmospheric deposition of chemical species produced in industry or CO_2 fertilization, they are not influenced by a direct human intervention.[15]

In addition, land that is previously managed remains in the managed land base for 20 years before re-classifying the land as unmanaged in order to account for legacy effects of management on C stocks.

Land-Use Categories

As with the definition of managed lands, IPCC (2006) provides general non-prescriptive definitions for the six main land-use categories: Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land. In order to reflect national circumstances, country-specific definitions have been developed, based predominantly on criteria used in the land-use surveys for the United States. Specifically, the definition of Forest Land is based on the FIA definition of forest,[16] while definitions of Cropland, Grassland, and Settlements are based on the NRI.[17] The definitions for Other Land and Wetlands are based on the IPCC (2006) definitions for these categories.

- *Forest Land*: A land-use category that includes areas at least 120 feet (36.6 meters) wide and at least one acre (0.4 hectare) in size with at least 10 percent cover (or equivalent stocking) by live trees including land that formerly had such tree cover and that will be naturally or artificially regenerated. Trees are woody plants having a more or less erect perennial stem(s) capable of achieving at least 3 inches (7.6 cm) in diameter at breast height, or 5 inches (12.7 cm) diameter at root collar, and a height of 16.4 feet (5 meters) at maturity in situ. Forest Land includes all areas recently having such conditions and currently regenerating or capable of attaining such condition in the near future. Forest Land also includes transition zones, such as areas between forest and non-forest lands that have at least 10 percent cover (or equivalent stocking) with live trees and forest areas adjacent to urban and built-up lands. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if they are less than 120 feet (36.6 meters) wide or an acre (0.4 hectare) in size. Forest Land does not include land that is predominantly under agricultural or urban land use (Oswalt et al. 2014).
- *Cropland*: A land-use category that includes areas used for the production of adapted crops for harvest; this category includes both cultivated and non-cultivated lands.[18] Cultivated crops include row crops or close-grown crops and also hay or pasture in rotation with cultivated crops. Non-cultivated cropland includes continuous hay, perennial crops (e.g., orchards) and horticultural cropland. Cropland also includes land with agroforestry, such as alley cropping and windbreaks,[19] if the dominant use is crop production. Lands in temporary fallow or enrolled in conservation reserve programs (i.e., set-asides[20]) are also classified as Cropland, as long as these areas do not meet the Forest Land criteria. Roads through Cropland, including interstate highways, state highways, other paved roads, gravel roads, dirt roads, and railroads are excluded from Cropland area estimates and are, instead, classified as Settlements.
- *Grassland*: A land-use category on which the plant cover is composed principally of grasses, grass-like plants (i.e., sedges and rushes), forbs, or shrubs suitable for grazing and browsing, and includes both pastures and native rangelands.[21] This includes areas where practices such as clearing, burning, chaining, and/or chemicals are applied to maintain the grass vegetation. Savannas, some wetlands and deserts, in

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[15] There are some areas, such as Forest Land and Grassland in Alaska that are classified as unmanaged land due to the remoteness of their location.

[16] See <http://socrates.lv-hrc.nevada.edu/fia/ab/issues/pending/glossary/Glossary_5_30_06.pdf>.

[17] See <http://www.nrcs.usda.gov/wps/portal/nrcs/site/national/home>.

[18] A minor portion of Cropland occurs on federal lands, and is not currently included in the C stock change inventory. A planned improvement is underway to include these areas in future C inventories.

[19] Currently, there is no data source to account for biomass C stock change associated with woody plant growth and losses in alley cropping systems and windbreaks in cropping systems, although these areas are included in the cropland land base.

[20] A set-aside is cropland that has been taken out of active cropping and converted to some type of vegetative cover, including, for example, native grasses or trees.

[21] Grasslands on federal lands are included in the managed land base, but C stock changes are not estimated on these lands. Federal grassland areas have been assumed to have negligible changes in C due to limited land-use and management change, but planned improvements are underway to further investigate this issue and include these areas in future C inventories.

addition to tundra are considered Grassland.[22] Woody plant communities of low forbs and shrubs, such as mesquite, chaparral, mountain shrub, and pinyon-juniper, are also classified as Grassland if they do not meet the criteria for Forest Land. Grassland includes land managed with agroforestry practices, such as silvipasture and windbreaks, if the land is principally grasses, grass-like plants, forbs, and shrubs suitable for grazing and browsing, and assuming the stand or woodlot does not meet the criteria for Forest Land. Roads through Grassland, including interstate highways, state highways, other paved roads, gravel roads, dirt roads, and railroads are excluded from Grassland and are, instead, classified as Settlements.

- *Wetlands*: A land-use category that includes land covered or saturated by water for all or part of the year, in addition to the areas of lakes, reservoirs, and rivers. Managed Wetlands are those where the water level is artificially changed, or were created by human activity. Certain areas that fall under the managed Wetlands definition are included in other land uses based on the IPCC guidance, including Cropland (drained wetlands for crop production and also systems that are flooded for most or just part of the year, such as rice cultivation and cranberry production), Grassland (drained wetlands dominated by grass cover), and Forest Land (including drained or un-drained forested wetlands).
- *Settlements*: A land-use category representing developed areas consisting of units of 0.25 acres (0.1 ha) or more that includes residential, industrial, commercial, and institutional land; construction sites; public administrative sites; railroad yards; cemeteries; airports; golf courses; sanitary landfills; sewage treatment plants; water control structures and spillways; parks within urban and built-up areas; and highways, railroads, and other transportation facilities. Also included are tracts of less than 10 acres (4.05 ha) that may meet the definitions for Forest Land, Cropland, Grassland, or Other Land but are completely surrounded by urban or built-up land, and so are included in the Settlements category. Rural transportation corridors located within other land uses (e.g., Forest Land, Cropland, and Grassland) are also included in Settlements.
- *Other Land*: A land-use category that includes bare soil, rock, ice, and all land areas that do not fall into any of the other five land-use categories, which allows the total of identified land areas to match the managed land base. Following the guidance provided by the IPCC (2006), C stock changes are not estimated for Other Lands because these areas are largely devoid of biomass, litter and soil C pools.

Land-Use Data Sources: Description and Application to U.S. Land Area Classification

U.S. Land-Use Data Sources

The three main sources for land-use data in the United States are the NRI, FIA, and the NLCD (Table 6-6). These data sources are combined to account for land use in all 50 states. FIA and NRI data are used when available for an area because the surveys contain additional information on management, site conditions, crop types, biometric measurements, and other data from which to estimate C stock changes on those lands. If NRI and FIA data are not available for an area, however, then the NLCD product is used to represent the land use.

Table 6-6: Data Sources Used to Determine Land Use and Land Area for the Conterminous United States, Hawaii, and Alaska

	NRI	FIA	NLCD
Forest Land			
Conterminous United States			
Non-Federal		•	
Federal		•	

[22] IPCC (2006) guidelines do not include provisions to separate desert and tundra as land categories.

Hawaii			
	Non-Federal	•	
	Federal		•
Alaska			
	Non-Federal		•
	Federal		•
Croplands, Grasslands, Other Lands, Settlements, and Wetlands			
Conterminous United States			
	Non-Federal	•	
	Federal		•
Hawaii			
	Non-Federal	•	
	Federal		•
Alaska			
	Non-Federal		•
	Federal		•

National Resources Inventory

For the Inventory, the NRI is the official source of data on all land uses on non-federal lands in the conterminous United States and Hawaii (except Forest Land), and is also used as the resource to determine the total land base for the conterminous United States and Hawaii. The NRI is a statistically-based survey conducted by the USDA Natural Resources Conservation Service and is designed to assess soil, water, and related environmental resources on non-federal lands. The NRI has a stratified multi-stage sampling design, where primary sample units are stratified on the basis of county and township boundaries defined by the United States Public Land Survey (Nusser and Goebel 1997). Within a primary sample unit (typically a 160 acre [64.75 hectare] square quarter-section), three sample points are selected according to a restricted randomization procedure. Each point in the survey is assigned an area weight (expansion factor) based on other known areas and land-use information (Nusser and Goebel 1997). The NRI survey utilizes data derived from remote sensing imagery and site visits in order to provide detailed information on land use and management, particularly for croplands and grasslands, and is used as the basis to account for C stock changes in agricultural lands (except federal Grasslands). The NRI survey was conducted every 5 years between 1982 and 1997, but shifted to annualized data collection in 1998. The land use between five-year periods from 1982 and 1997 are assumed to be the same for a five-year time period if the land use is the same at the beginning and end of the five-year period. (Note: most of the data has the same land use at the beginning and end of the five-year periods.) If the land use had changed during a five-year period, then the change is assigned at random to one of the five years. For crop histories, years with missing data are estimated based on the sequence of crops grown during years preceding and succeeding a missing year in the NRI history. This gap-filling approach allows for development of a full time series of land-use data for non-federal lands in the conterminous United States and Hawaii. This Inventory incorporates data through 2007 from the NRI.

Forest Inventory and Analysis

The FIA program, conducted by the USFS, is another statistically-based survey for the conterminous United States, and the official source of data on Forest Land area and management data for the Inventory in this region of the country. FIA engages in a hierarchical system of sampling, with sampling categorized as Phases 1 through 3, in which sample points for phases are subsets of the previous phase. Phase 1 refers to collection of remotely-sensed data (either aerial photographs or satellite imagery) primarily to classify land into forest or non-forest and to identify landscape patterns like fragmentation and urbanization. Phase 2 is the collection of field data on a network of ground plots that enable classification and summarization of area, tree, and other attributes associated with forest-land uses. Phase 3 plots are a subset of Phase 2 plots where data on indicators of forest health are measured. Data from all three phases are also used to estimate C stock changes for Forest Land. Historically, FIA inventory surveys have been conducted periodically, with all plots in a state being measured at a frequency of every five to 14 years. A new national plot design and annual sampling design was introduced by FIA about ten years ago. Most states, though, have only recently been brought into this system. Annualized sampling means that a portion of plots throughout each state is sampled each year, with the goal of measuring all plots once every five years. See Annex

3.13 to see the specific survey data available by state. The most recent year of available data varies state by state (range of most recent data is from 2012 through 2013; see Table A-246).

National Land Cover Dataset

Though NRI provides land-area data for both federal and non-federal lands in the conterminous United States and Hawaii, it only includes land-use data on non-federal lands, and FIA only records data for forest land.[23] Consequently, major gaps exist when the datasets are combined, such as federal grassland operated by Bureau of Land Management (BLM), USDA, and National Park Service, as well as Alaska.[24] The NLCD is used as a supplementary database to account for land use on federal lands that are not included in the NRI and FIA databases. The NLCD land-cover classification scheme, available for 1992, 2001, 2006, and 2011 has been applied over the conterminous United States (Homer et al. 2007), and also for Alaska and Hawaii in 2001. For the conterminous United States, the NLCD Land Cover Change Products for 2001, 2006, and 2011 were used in order to represent both land use and land-use change for federal lands (Fry et al. 2011, Homer et al. 2007, Jin et al. 2013). The NLCD products are based primarily on Landsat Thematic Mapper imagery. The NLCD contains 21 categories of land-cover information, which have been aggregated into the IPCC land-use categories, and the data are available at a spatial resolution of 30 meters. The federal land portion of the NLCD was extracted from the dataset using the federal land area boundary map from the National Atlas (U.S. Department of Interior 2005). This map represents federal land boundaries in 2005, so as part of the analysis, the federal land area was adjusted annually based on the NRI federal land area estimates (i.e., land is periodically transferred between federal and non-federal ownership). Consequently, the portion of the land base categorized with NLCD data varied from year to year, corresponding to an increase or decrease in the federal land base. The NLCD is strictly a source of land-cover information, however, and does not provide the necessary site conditions, crop types, and management information from which to estimate C stock changes on those lands.

As part of Quality Assurance and Quality Control (QA/QC), the land base derived from the NRI, FIA, and NLCD was compared to the Topologically Integrated Geographic Encoding and Referencing (TIGER) survey (U.S. Census Bureau 2010). The U.S. Census Bureau gathers data on the U.S. population and economy, and has a database of land areas for the country. The land area estimates from the U.S. Census Bureau differ from those provided by the land-use surveys used in the Inventory because of discrepancies in the reporting approach for the Census and the methods used in the NRI, FIA, and NLCD. The area estimates of land-use categories, based on NRI, FIA, and NLCD, are derived from remote sensing data instead of the land survey approach used by the U.S. Census Survey. More importantly, the U.S. Census Survey does not provide a time series of land-use change data or land management information. Consequently, the U.S. Census Survey was not adopted as the official land area estimate for the Inventory. Rather, the NRI, FIA, and NLCD datasets were adopted because this database provides full coverage of land area and land use for the conterminous United States, Alaska, and Hawaii, in addition to management and other data relevant for the Inventory. Regardless, the total difference between the U.S. Census Survey and the combined NRI, FIA, and NLCD data is about 22 million hectares for the total U.S. land base of about 936 million hectares currently included in the Inventory, or a 2.4 percent difference. Much of this difference is associated with open waters in coastal regions and the Great Lakes, which is included in the Census.

Managed Land Designation

Lands are designated as managed in the United States based on the definitions provided earlier in this section. In order to apply the definitions in an analysis of managed land, the following criteria are used:

- All Croplands and Settlements are designated as managed so only Grassland, Forest Land or Other Lands may be designated as unmanaged land;[25]
- All Forest Land with active fire protection are considered managed;

[23] FIA does collect some data on non-forest land use, but these are held in regional databases versus the national database. The status of these data is being investigated.

[24] The FIA and NRI survey programs also do not include U.S. Territories with the exception of non-federal lands in Puerto Rico, which are included in the NRI survey. Furthermore, NLCD does not include coverage for all U.S. Territories.

[25] A planned improvement is underway to deal with an exception for Wetlands which includes both managed and unmanaged lands based on the definitions for the current U.S. Land Representation Assessment.

- All Grassland is considered managed at a county scale if there are livestock in the county;[26] other areas are considered managed if accessible based on the proximity to roads and other transportation corridors, and/or infrastructure;
- Protected lands maintained for recreational and conservation purposes are considered managed (managed by public and private organizations);
- Lands with active and/or past resource extraction are considered managed; and
- Lands that were previously managed but subsequently classified as unmanaged remain in the managed land base for 20 years following the conversion to account for legacy effects of management on C stocks.

The analysis of managed lands is conducted using a geographic information system. Lands that are used for crop production or settlements are determined from the NLCD (Fry et al. 2011, Homer et al. 2007, Jin et al. 2013). Lands with active fire management are determined from maps of federal and state management plans from the National Atlas (U.S. Department of Interior 2005) and Alaska Interagency Fire Management Council (1998). It is noteworthy that all forest lands in the conterminous United States have active fire protection, and are therefore designated as managed regardless of accessibility or other criteria. The designation of grasslands as managed is determined based on USDA National Agricultural Statistics Service livestock population data at the county scale (U.S. Department of Agriculture 2011). Accessibility is evaluated based on a 10-km buffer surrounding road and train transportation networks using the ESRI Data and Maps product (ESRI 2008), and a 10-km buffer surrounding settlements using NLCD. Lands maintained for recreational purposes are determined from analysis of the Protected Areas Database (U.S. Geological Survey 2012). However, protected areas that are not accessible to human intervention, including no suppression of disturbances or extraction of resources, are not included in the managed land base. Multiple data sources are used to determine lands with active resource extraction: Alaska Oil and Gas Information System (Alaska Oil and Gas Conservation Commission 2009), Alaska Resource Data File (U.S. Geological Survey 2012), Active Mines and Mineral Processing Plants (U.S. Geological Survey 2005), and Coal Production and Preparation Report (U.S. Energy Information Administration 2011). A buffer of 3,300 and 4.000 meters is assumed around petroleum extraction and mine locations, respectively, to account for the footprint of operation and impacts of activities on the surrounding landscape. The resulting managed land area is overlaid on the NLCD to estimate the area of managed land by land use for both federal and non-federal lands. The remaining land represents the unmanaged land base.

Approach for Combining Data Sources

The managed land base in the United States has been classified into the thirty-six IPCC land-use categories using definitions developed to meet national circumstances, while adhering to IPCC (2006).[27] In practice, the land was initially classified into a variety of land-use categories within the NRI, FIA, and NLCD datasets, and then aggregated into the thirty-six broad land use and land-use-change categories identified in IPCC (2006). All three datasets provide information on forest land areas in the conterminous United States, but the area data from FIA serve as the official dataset for estimating Forest Land use areas in the conterminous United States.

Therefore, another step in the analysis is to address the inconsistencies in the representation of the forest land among the three databases. NRI and FIA have different criteria for classifying forest land in addition to different sampling designs, leading to discrepancies in the resulting estimates of Forest Land area on non-federal land in the conterminous United States. Similarly, there are discrepancies between the NLCD and FIA data for defining and classifying Forest Land on federal lands. In addition, dependence exists between the Forest Land area and the amount of land designated as other land uses in both the NRI and the NLCD, such as the amount of Grassland, Cropland, and Wetlands, relative to the Forest Land area. This results in inconsistencies among the three databases for estimated Forest Land area, as well as for the area estimates for other land-use categories. FIA is the main database for forest statistics, and consequently, the NRI and NLCD were adjusted to achieve consistency with FIA estimates of Forest Land in the conterminous United States. The adjustments were made at a state-scale, and it was assumed that the majority of the discrepancy in forest area was associated with an under- or over-prediction of

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[26] Assuming all grasslands are grazed in a county with livestock is a conservation assumption about human impacts on grasslands. Currently, detailed information on grazing at sub-county scales is not available for the United States to make a finer delineation of managed land.

[27] Definitions are provided in the previous section.

Grassland and Wetland area in the NRI and NLCD due to differences in forest land definitions. Specifically, the forest land area for a given state according to the NRI and NLCD was adjusted to match the FIA estimates of Forest Land for non-federal and federal land in *Forest Lands Remaining Forest Lands*, respectively. In a second step, corresponding increases or decreases were made in the area estimates of Grassland and Wetland from the NRI and NLCD, *Grasslands Remaining Grasslands* and *Wetlands Remaining Wetlands*, in order to balance the change in forest area, and therefore not change the overall amount of managed land within an individual state. The adjustments were based on the proportion of land within each of these land-use categories at the state level. (i.e., a higher proportion of Grassland led to a larger adjustment in Grassland area).

The modified NRI data are then aggregated to provide the land-use and land-use change data for non-federal lands in the conterminous United States, and the modified NLCD data are aggregated to provide the land use and land-use change data for federal lands. Data for all land uses in Hawaii are based on NRI for non-federal lands and on NLCD for federal lands. Land use data in Alaska are based solely on the NLCD data (Table 6-6). The result is land use and land-use change data for the conterminous United States, Hawaii, and Alaska.[28]

A summary of the details on the approach used to combine data sources for each land use are described below.

- *Forest Land*: Both non-federal and federal forest lands in both the continental United States and coastal Alaska are covered by FIA. FIA is used as the basis for both Forest Land area data as well as to estimate C stocks and fluxes on Forest Land. Interior Alaska is not currently surveyed by FIA so forest land in Alaska is evaluated with 2001 NLCD. NRI is being used in the current report to provide Forest Land areas on non-federal lands in Hawaii, but FIA data will be collected in Hawaii in the future.
- *Cropland*: Cropland is classified using the NRI, which covers all non-federal lands within 49 states (excluding Alaska), including state and local government-owned land as well as tribal lands. NRI is used as the basis for both Cropland area data as well as to estimate soil C stocks and fluxes on Cropland. NLCD 2001 is used to determine Cropland area in Alaska.
- *Grassland*: Grassland on non-federal lands is classified using the NRI within 49 states (excluding Alaska), including state and local government-owned land as well as tribal lands. NRI is used as the basis for both Grassland area data as well as to estimate soil C stocks and fluxes on Grassland. Grassland on federal Bureau of Land Management lands, Department of Defense lands, National Parks, and within USFS lands are covered by the NLCD. NLCD is used to estimate the areas of federal and non-federal grasslands in Alaska.
- *Wetlands*: NRI captures wetlands on non-federal lands within 49 states (excluding Alaska), while federal wetlands and wetlands in Alaska are covered by the NLCD. This currently includes both managed and unmanaged wetlands as no database has yet been applied to make this distinction. See the Planned Improvements section for details.
- *Settlements*: NRI captures non-federal settlement area in 49 states (excluding Alaska). If areas of Forest Land or Grassland under 10 acres (4.05 ha) are contained within settlements or urban areas, they are classified as Settlements (urban) in the NRI database. If these parcels exceed the 10 acre (4.05 ha) threshold and are Grassland, they will be classified as such by NRI. Regardless of size, a forested area is classified as non-forest by FIA if it is located within an urban area. Settlements on federal lands and in Alaska are covered by NLCD.
- *Other Land*: Any land not falling into the other five land-use categories and, therefore, categorized as Other Land is classified using the NRI for non-federal areas in the 49 states (excluding Alaska) and NLCD for the federal lands and Alaska.

Some lands can be classified into one or more categories due to multiple uses that meet the criteria of more than one definition. However, a ranking has been developed for assignment priority in these cases. The ranking process is from highest to lowest priority, in the following manner:

Settlements > *Cropland* > *Forest Land* > *Grassland* > *Wetlands* > *Other Land*

[28] Only one year of data are currently available for Alaska so there is no information on land-use change for this state.

Settlements are given the highest assignment priority because they are extremely heterogeneous with a mosaic of patches that include buildings, infrastructure, and travel corridors, but also open grass areas, forest patches, riparian areas, and gardens. The latter examples could be classified as Grassland, Forest Land, Wetlands, and Cropland, respectively, but when located in close proximity to settlement areas they tend to be managed in a unique manner compared to non-settlement areas. Consequently, these areas are assigned to the Settlements land-use category. Cropland is given the second assignment priority, because cropping practices tend to dominate management activities on areas used to produce food, forage, or fiber. The consequence of this ranking is that crops in rotation with pasture will be classified as Cropland, and land with woody plant cover that is used to produce crops (e.g., orchards) is classified as Cropland, even though these areas may meet the definitions of Grassland or Forest Land, respectively. Similarly, Wetlands are considered Croplands if they are used for crop production, such as rice or cranberries. Forest Land occurs next in the priority assignment because traditional forestry practices tend to be the focus of the management activity in areas with woody plant cover that are not croplands (e.g., orchards) or settlements (e.g., housing subdivisions with significant tree cover). Grassland occurs next in the ranking, while Wetlands then Other Land complete the list.

The assignment priority does not reflect the level of importance for reporting GHG emissions and removals on managed land, but is intended to classify all areas into a discrete land use. Currently, the IPCC does not make provisions in the guidelines for assigning land to multiple uses. For example, a wetland is classified as Forest Land if the area has sufficient tree cover to meet the stocking and stand size requirements. Similarly, wetlands are classified as Cropland if they are used for crop production, such as rice or cranberries, or as Grassland if they are composed principally of grasses, grass-like plants (i.e., sedges and rushes), forbs, or shrubs suitable for grazing and browsing. Regardless of the classification, emissions from these areas are included in the Inventory if the land is considered managed and presumably impacted by anthropogenic activity in accordance with the guidance provided in IPCC (2006).

Recalculations Discussion

Relative to the previous Inventory, new data were incorporated from FIA on forestland areas, which were used to make minor adjustments to the time series. The managed land base was further refined this year with the new implementation criteria incorporating lands protected for recreation in addition to lands with mineral and petroleum extraction. This change increased the managed land base in Alaska, but had limited impact on the managed land base in the conterminous United States.

Planned Improvements

A key planned improvement is to fully incorporate area data by land-use type for U.S. Territories into the Inventory. Fortunately, most of the managed land in the United States is included in the current land-use statistics, but a complete accounting is a key goal for the near future. Preliminary land-use area data by land-use category are provided in Box 6-2: Preliminary Estimates of Land Use in U.S. Territories for the U.S. Territories.

Box 6-2: Preliminary Estimates of Land Use in U.S. Territories

Several programs have developed land cover maps for U.S. Territories using remote sensing imagery, including the Gap Analysis program, Caribbean Land Cover project, National Land Cover dataset, USFS Pacific Islands Imagery Project, and the National Oceanic and Atmospheric Administration (NOAA) Coastal Change Analysis Program. Land-cover data can be used to inform a land-use classification if there is a time series to evaluate the dominate practices. For example, land that is principally used for timber production with tree cover over most of the time series is classified as forest land even if there are a few years of grass dominance following timber harvest. These products were reviewed and evaluated for use in the national Inventory as a step towards implementing a planned improvement to include U.S. Territories in the land representation for the Inventory. Recommendations are to use the NOAA Coastal Change Analysis Program (C-CAP) Regional Land Cover Database for the smaller island Territories (U.S. Virgin Islands, Guam, Northern Marianas Islands, and American Samoa) because this program is an ongoing and therefore will be continually updated. The C-CAP product does not cover the entire territory of Puerto Rico so the NLCD was used for this area. The final selection of a land-cover product for these Territories is still under discussion. Results are presented below (in hectares). The total land area of all U.S. Territories is 1.05 million hectares, representing 0.1 percent of the total land base for the United States.

Table 6-7: Total Land Area (Hectares) by Land-Use Category for U.S. Territories.

	Puerto Rico	U.S. Virgin Islands	Guam	Northern Marianas Islands	American Samoa	Total
Cropland	19,712	138	236	289	389	20,764
Forest Land	404,004	13,107	24,650	25,761	15,440	482,962
Grasslands	299,714	12,148	15,449	13,636	1,830	342,777
Other Land	5,502	1,006	1,141	5,186	298	13,133
Settlements	130,330	7,650	11,146	3,637	1,734	154,496
Wetlands	24,525	4,748	1,633	260	87	31,252
Total	**883,788**	**38,796**	**54,255**	**48,769**	**19,777**	**1,045,385**

Additional work will be conducted to reconcile differences in Forest Land estimates between the NRI and FIA, evaluating the assumption that the majority of discrepancies in Forest Land areas are associated with an over- or under-estimation of Grassland and Wetland area. In some regions of the United States, a discrepancy in Forest Land areas between NRI and FIA may be associated with an over- or under-prediction of other land uses. This improvement would include an analysis designed to develop region-specific adjustments.

There are also other databases that may need to be reconciled with the NRI and NLCD datasets, particularly for Settlements. Urban area estimates, used to produce C stock and flux estimates from urban trees, are currently based on population data (1990, 2000, and 2010 U.S. Census data). Using the population statistics, "urban clusters" are defined as areas with more than 500 people per square mile. The USFS is currently moving ahead with an urban forest inventory program so that urban forest area estimates will be consistent with FIA forest area estimates outside of urban areas, which would be expected to reduce omissions and overlap of forest area estimates along urban boundary areas.

As adopted by the UNFCCC, new guidance in the *2013 Supplement to the 2006 Guidelines for National Greenhouse Gas Inventories: Wetlands* will be implemented in the Inventory. This will likely have implications for the classification of managed and unmanaged wetlands in the Inventory report. More detailed wetlands datasets will also be evaluated and integrated into the analysis in order to implement the new guidance.

6.2 Forest Land Remaining Forest Land

Changes in Forest Carbon Stocks (IPCC Source Category 4A1)

For estimating carbon (C) stocks or stock change (flux), C in forest ecosystems can be divided into the following five storage pools (IPCC 2006):

- Aboveground biomass, which includes all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage. This category includes live understory.
- Belowground biomass, which includes all living biomass of coarse living roots greater than 2 mm diameter.
- Dead wood, which includes all non-living woody biomass either standing, lying on the ground (but not including litter), or in the soil.
- Litter, which includes the litter, fumic, and humic layers, and all non-living biomass with a diameter less than 7.5 cm at transect intersection, lying on the ground.
- Soil organic C (SOC), including all organic material in soil to a depth of 1 meter but excluding the coarse roots of the aboveground pools.

In addition, there are two harvested wood pools to account for when estimating C flux:

- Harvested wood products (HWP) in use.

- HWP in solid waste disposal sites (SWDS).

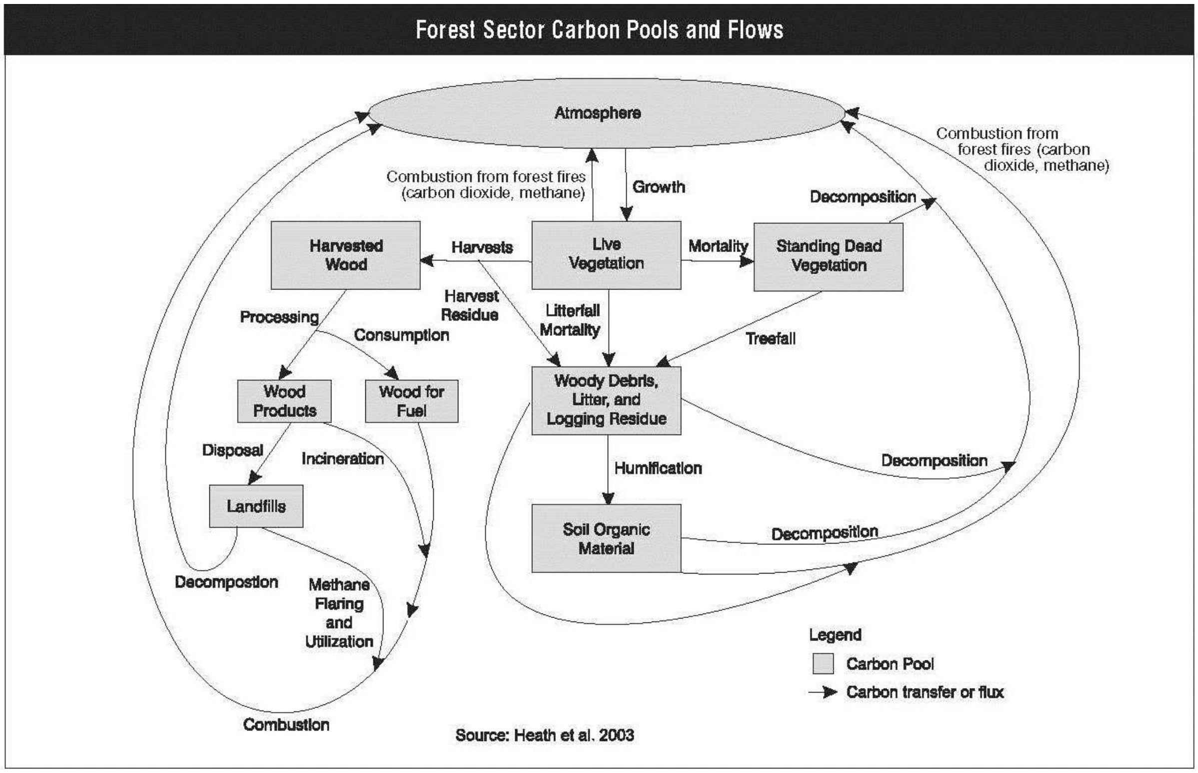
Carbon is continuously cycled among these storage pools and between forest ecosystems and the atmosphere as a result of biological processes in forests (e.g., photosynthesis, respiration, decomposition, and disturbances such as fires or pest outbreaks) and anthropogenic activities (e.g., harvesting, thinning, and replanting). As trees photosynthesize and grow, C is removed from the atmosphere and stored in living tree biomass. As trees die and otherwise deposit litter and debris on the forest floor, C is released to the atmosphere and also is transferred to the soil by organisms that facilitate decomposition.

The net change in forest C is not equivalent to the net flux between forests and the atmosphere because timber harvests do not cause an immediate flux of all harvested biomass C to the atmosphere. Instead, harvesting transfers a portion of the C stored in wood to a "product pool." Once in a product pool, the C is emitted over time as CO_2 when the wood product combusts or decays. The rate of emission varies considerably among different product pools. For example, if timber is harvested to produce energy, combustion releases C immediately, and these emissions are reported for information purposes in the Energy Sector with the harvest (i.e., the associated reduction in forest carbon stocks) and subsequent combustion implicitly accounted for under the Land Use, Land-Use Change (LULUCF) Sector (i.e., the harvested timber does not enter the HWP pools). Conversely, if timber is harvested and used as lumber in a house, it may be many decades or even centuries before the lumber decays and C is released to the atmosphere. If wood products are disposed of in SWDS, the C contained in the wood may be released many years or decades later, or may be stored almost permanently in the SWDS. These latter fluxes are also accounted for under the LULUCF Sector.

This section quantifies the net changes in C stocks in the five forest C pools and two harvested wood pools. The basic methodology for determining C stock and stock-change relies on data from the extensive inventories of U.S. forest lands, and improvements in these inventories over time are reflected in the estimates (Heath et al. 2011, Heath 2012). The net change in stocks for each pool is estimated, and then the changes in stocks are summed for all pools to estimate total net flux. The focus on C implies that all C-based greenhouse gases are included, and the focus on stock change suggests that specific ecosystem fluxes do not need to be separately itemized in this report. Changes in C stocks from disturbances, such as forest fires, are implicitly included in the net changes. For instance, an inventory conducted after fire counts only the trees that are left. Therefore, changes in C stocks from natural disturbances, such as wildfires, pest outbreaks, and storms, are implicitly accounted for in the forest inventory approach; however, they are highly variable from year to year. Wildfire events are typically the most severe but other natural disturbance events can result in large C stock losses that are time- and location- specific. The IPCC (2006) recommends reporting changes in C stocks from forest lands according to several land-use types and conversions, specifically *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*. Research is ongoing to track C across a matrix of land-uses and land-use changes. Until such time that reliable and comprehensive estimates of C across the land-use matrix can be produced, net changes in all forest-related land, including non-forest land converted to forest and forests converted to non-forest, are reported here in the *Forest Land Remaining Forest Land* Sector (see the Planned Improvements section for more details).

Forest C storage pools, and the flows between them via emissions, sequestration, and transfers, are shown in Figure 6-2. In the figure, boxes represent forest C storage pools and arrows represent flows between storage pools or between storage pools and the atmosphere. Note that the boxes are not identical to the five storage pools identified in the *2006 IPCC Guidelines*. Instead, the storage pools identified have been refined in this graphic to better illustrate the processes that result in transfers of C from one pool to another, and emissions to as well as uptake from the atmosphere.

Figure 6-2: Forest Sector C Pools and Flows

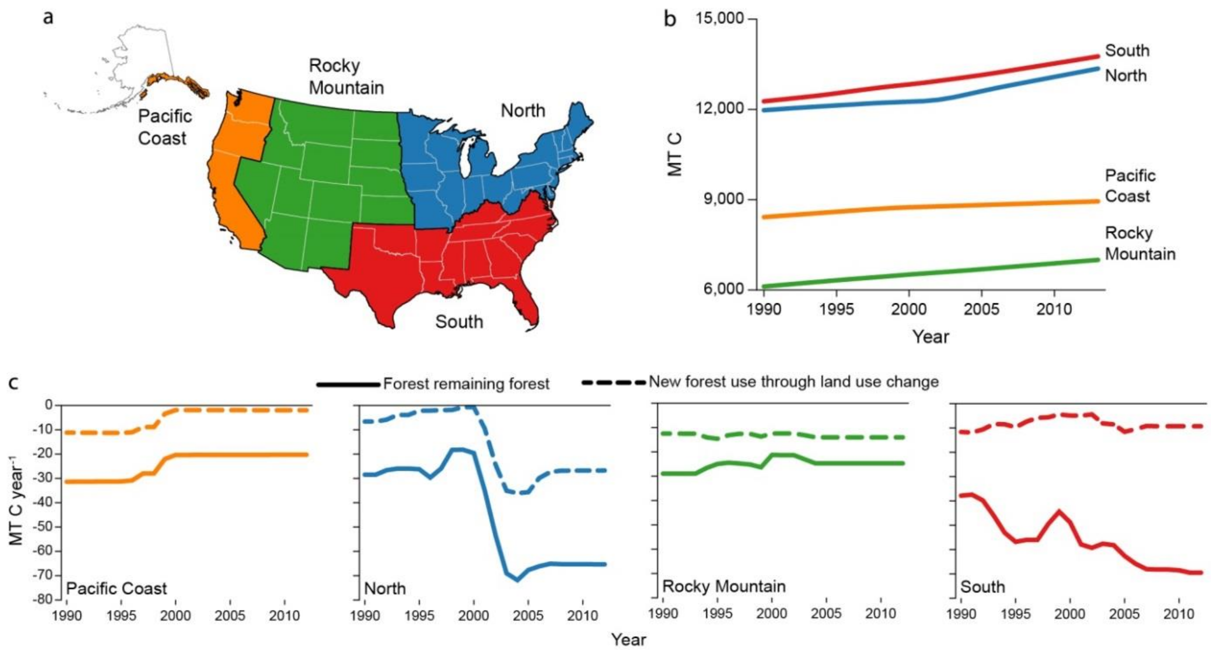


Approximately 34 percent of the U.S. land area is estimated to be forested (Oswalt et al. 2014). The most-recent forest inventories from each of the conterminous 48 states (USDA Forest Service 2014a, 2014b, and see Annex Table A-246) include an estimated 264 million hectares of forest land that are considered managed and are included in this inventory. An additional 6 million hectares of southeast and south central Alaskan forest are inventoried and are included here. Some differences exist in forest land defined in Oswalt et al. (2014) and the forest land included in this report, which is based on the USDA Forest Service (2014b) forest inventory. Survey data are not yet available for Hawaii and interior Alaska, but estimates of these areas are included in Oswalt et al. (2014). Updated survey data for central and western forest land in both Oklahoma and Texas have only recently become available, and these forests contribute to overall C stocks reported below. While Hawaii and U.S. territories have relatively small areas of forest land and thus may not influence the overall C budget substantially, these regions will be added to the C budget as sufficient data become available. Agroforestry systems are also not currently accounted for in the inventory, since they are not explicitly inventoried by either the FIA program of the USDA Forest Service or the NRI of the USDA Natural Resources Conservation Service (Perry et al. 2005).

An estimated 68 percent (211 million hectares) of U.S. forests in Alaska and the conterminous United States are classified as timberland, meaning they meet minimum levels of productivity and have not been removed from production. Ten percent of Alaskan forests and 80 percent of forests in the conterminous United States are classified as timberlands. Of the remaining non-timberland forests, 30 million hectares are reserved forest lands (withdrawn by law from management for production of wood products) and 69 million hectares are lower productivity forest lands (Oswalt et al. 2014). Historically, the timberlands in the conterminous 48 states have been more frequently or intensively surveyed than other forest lands.

Estimates of forest land area declined by approximately 8 million hectares over the period from the early 1960s to the late 1980s. Since then, forest area has increased by about 14 million hectares (Oswalt et al. 2014). Current trends in the managed forest area represented here increased by an average annual rate of 0.1 percent (see Annex Table A-248). In addition to the increase in forest area, the major influences on the current net C flux from forest land are management activities and the ongoing impacts of previous land-use changes. These activities affect the net flux of C by altering the amount of C stored in forest ecosystems. For example, intensified management of forests that leads to an increased rate of growth may increase the eventual biomass density of the forest, thereby increasing the uptake and storage of C.[29] Though harvesting forests removes much of the aboveground C, on average the estimated volume of annual net growth nationwide is about double the volume of annual removals on timberlands (Oswalt et al. 2014). The reversion of cropland or grassland to forest land increases C storage in biomass, forest floor, and soils. Emerging research into forest ecosystem C stock change for forest remaining forest versus land-use change transfers to the forest land use suggest that forest ecosystem C accretion continues at steady rates in most regions of the United States (Figure 6-3) due to the aforementioned drivers. In concert with this trend, conversion of croplands and grasslands to forest lands continues to facilitate net increases in forest C stocks over time especially in northern and southern regions. The net effects of forest management and the effects of land-use change involving forest land are captured in the estimates of C stocks and fluxes presented in this chapter.

Figure 6-3: Forest Ecosystem Carbon (All Pools) Stocks and Stock Change (1990-2013)



Forest ecosystem C (all pools) stocks and stock change (1990–2013) analysis attributable to forest remaining forest and land-use change transfers to forests: (a) Resource planning act assessment regions, (b) forest ecosystem stocks by region, (c) annual stock change in forest ecosystem C by region decomposed into net transfers into the forest C pool through land-use change and the net C accumulation in forests remaining forest (including disturbance related mortality and growth) (for analytical techniques see Coulston et al. in review and Wear and Coulston 2014).

In the United States, improved forest management practices, the regeneration of previously cleared forest areas, and timber harvesting and use have resulted in net uptake (i.e., net sequestration) of C each year from 1990 through 2013. The rate of forest clearing in the 17th century following European settlement had slowed by the late 19th century. Through the later part of the 20th century many areas of previously forested land in the United States were allowed to revert to forests or were actively reforested. The impacts of these land-use changes still influence C fluxes from these forest lands. More recently, the 1970s and 1980s saw a resurgence of federally-sponsored forest management programs (e.g., the Forestry Incentive Program) and soil conservation programs (e.g., the Conservation Reserve Program), which have focused on tree planting, improving timber management activities, combating soil erosion, and converting marginal cropland to forests. In addition to forest regeneration and management, forest

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[29] The term "biomass density" refers to the mass of live vegetation per unit area. It is usually measured on a dry-weight basis. Dry biomass is 50 percent C by weight.

harvests have also affected net C fluxes. Because most of the timber harvested from U.S. forests is used in wood products, and many discarded wood products are disposed of in SWDS rather than by incineration, significant quantities of C in harvested wood are transferred to long-term storage pools rather than being released rapidly to the atmosphere (Skog 2008). The size of these long-term C storage pools has increased during the last century with the question arising as to how long the U.S. forests can remain a net C sink (Woodall et al. 2013).

Changes in C stocks in U.S. forests and harvested wood were estimated to account for net sequestration of 775.7 MMT CO_2 Eq. (211.5 MMT C) in 2013 (Table 6-8, Table 6-9, and Table 6-10). In addition to the net accumulation of C in harvested wood pools, sequestration is a reflection of net forest growth and increasing forest area over this period. Overall, estimates of average C in forest ecosystem biomass (aboveground and belowground) increased from 55 to 66 T C/ha between 1990 and 2014 (see Annex 3.13 for estimated average C densities by specific regions and forest types). Continuous, regular annual surveys are not available over the period for each state; therefore, estimates for non-survey years were derived by interpolation between known data points. Survey years vary from state to state, and national estimates are a composite of individual state surveys. Therefore, changes in sequestration over the interval 1990 to 2013 are the result of the sequences of new inventories for each state. Carbon in forest ecosystem biomass had the greatest effect on total change through increases in C density and total forest land. Management practices that increase C stocks on forest land, as well as afforestation and reforestation efforts, influence the trends of increased C densities in forests and increased forest land in the United States.

Estimated annual net additions to HWP C stock increased slightly between 2012 and 2013. Estimated net additions to solid-wood products in use increased a little with further recovery of the housing market, but additions to paper products in use declined. Estimated net additions to products in use for 2013 is about 20 percent of the level of net additions to products in use in 2007—prior to the recession. Estimated additions to landfills have been relatively stable over time.

Table 6-8: Estimated Net Annual Changes in C Stocks (MMT CO_2/yr) in Forest and Harvested Wood Pools

Carbon Pool	1990		2005		2009	2010	2011	2012	2013
Forest	**(507.7)**		**(704.4)**		**(710.6)**	**(704.9)**	**(704.9)**	**(704.9)**	**(704.9)**
Aboveground	(324.6)		(402.8)		(433.8)	(433.7)	(433.7)	(433.7)	(433.7)
Belowground	(63.2)		(79.3)		(87.3)	(87.4)	(87.4)	(87.4)	(87.4)
Dead Wood	(45.9)		(66.8)		(94.2)	(95.0)	(95.0)	(95.0)	(95.0)
Litter	(26.8)		(11.8)		(11.2)	(10.9)	(10.9)	(10.9)	(10.9)
Soil Organic C	(47.2)		(143.8)		(84.1)	(77.9)	(77.9)	(77.9)	(77.9)
Harvested Wood	**(131.8)**		**(102.7)**		**(54.3)**	**(60.5)**	**(68.9)**	**(68.2)**	**(70.8)**
Products in Use	(64.8)		(42.9)		6.6	0.4	(7.3)	(6.2)	(8.4)
SWDS	(67.0)		(59.8)		(60.9)	(60.9)	(61.6)	(62.0)	(62.3)
Total Net Flux	**(639.4)**		**(807.1)**		**(764.9)**	**(765.4)**	**(773.8)**	**(773.1)**	**(775.7)**

Note: Forest C stocks do not include forest stocks in U.S. territories, Hawaii, a portion of managed forests in Alaska, or trees on non-forest land (e.g., urban trees, agroforestry systems). Parentheses indicate net C sequestration (i.e., a net removal of C from the atmosphere). Total net flux is an estimate of the actual net flux between the total forest C pool and the atmosphere. Forest area estimates are based on interpolation and extrapolation of Inventory data as described in the text and in Annex 3.13. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding.

Table 6-9: Estimated Net Annual Changes in C Stocks (MMT C/yr) in Forest and Harvested Wood Pools

Carbon Pool	1990		2005		2009	2010	2011	2012	2013
Forest	**(138.5)**		**(192.1)**		**(193.8)**	**(192.2)**	**(192.2)**	**(192.2)**	**(192.2)**
Aboveground Biomass	(88.5)		(109.9)		(118.3)	(118.3)	(118.3)	(118.3)	(118.3)
Belowground Biomass	(17.2)		(21.6)		(23.8)	(23.8)	(23.8)	(23.8)	(23.8)
Dead Wood	(12.5)		(18.2)		(25.7)	(25.9)	(25.9)	(25.9)	(25.9)
Litter	(7.3)		(3.2)		(3.1)	(3.0)	(3.0)	(3.0)	(3.0)
Soil Organic C	(12.9)		(39.2)		(22.9)	(21.2)	(21.2)	(21.2)	(21.2)
Harvested Wood	**(35.9)**		**(28.0)**		**(14.8)**	**(16.5)**	**(18.8)**	**(18.6)**	**(19.3)**
Products in Use	(17.7)		(11.7)		1.8	0.1	(2.0)	(1.7)	(2.3)
SWDS	(18.3)		(16.3)		(16.6)	(16.6)	(16.8)	(16.9)	(17.0)

Total Net Flux	**(174.4)**	**(220.1)**	**(208.6)**	**(208.7)**	**(211.0)**	**(210.8)**	**(211.5)**

Note: Forest C stocks do not include forest stocks in U.S. territories, Hawaii, a portion of managed lands in Alaska, or trees on non-forest land (e.g., urban trees, agroforestry systems). Parentheses indicate net C sequestration (i.e., a net removal of C from the atmosphere). Total net flux is an estimate of the actual net flux between the total forest C pool and the atmosphere. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding.

Stock estimates for forest and harvested wood C storage pools are presented in Table 6-10. Together, the estimated aboveground live and forest soil pools account for a large proportion of total forest C stocks. The estimated C stocks summed for non-soil pools increased over time. Therefore, the estimated C sequestration was greater than C emissions from forests, as discussed above. Although not using the same pool delineations as this inventory submission, recent research into imputing FIA plot data across the coterminous United States allows spatial interpretation of forest C pools (Wilson et al. 2013). The imputed C density of individual forest ecosystem pools is highly variable across the diverse ecosystems of the United States (see Figure 6-5) highlighting the technical hurdles in refining C accounting across the matrix of changing land uses and ecosystem dynamics (e.g., temperate versus subtropical forests).

Table 6-10: Estimated Forest area (1,000 ha) and C Stocks (MMT C) in Forest and Harvested Wood Pools

	1990	2005	2009	2010	2011	2012	2013	2014
Forest Area (1000 ha)	*265,938*	*268,334*	*269,396*	*269,536*	*269,661*	*269,786*	*269,911*	*270,035*
Carbon Pools (MMT C)								
Forest	**36,309**	**38,429**	**39,214**	**39,408**	**39,600**	**39,792**	**39,985**	**40,177**
Aboveground Biomass	12,266	13,727	14,188	14,306	14,425	14,543	14,661	14,780
Belowground Biomass	2,430	2,717	2,809	2,833	2,857	2,881	2,904	2,928
Dead Wood	2,138	2,384	2,470	2,496	2,522	2,548	2,574	2,600
Litter	2,749	2,803	2,816	2,819	2,822	2,825	2,828	2,831
Soil Organic C	16,726	16,798	16,931	16,954	16,975	16,996	17,017	17,038
Harvested Wood	**1,859**	**2,325**	**2,431**	**2,446**	**2,462**	**2,481**	**2,500**	**2,520**
Products in Use	1,231	1,435	1,473	1,472	1,471	1,473	1,475	1,478
SWDS	628	890	958	974	991	1,008	1,025	1,042
Total C Stock	**38,168**	**40,754**	**41,645**	**41,854**	**42,062**	**42,273**	**42,485**	**42,697**

Note: Forest area and carbon stock estimates include all forest land in the conterminous 48 states plus managed forests in coastal Alaska (Figure 6-6), which is the current area encompassed by FIA survey data. A recent methodological change implemented to address missing forest area data in coastal Alaska resulted in discrepancies between the coastal Alaska managed forest area of 1990 through 2014, as contributes to this table, and the areas presented in Section 6.1 "Representation of the United S Land Base". Coastal Alaska managed forest lands contributing to this table changed linearly from 5.77 million hectares in 1990 to 5.86 million hectares in 2014. The estimates used for Section 6 changed linearly from 5.48 million hectares in 1990 to 5.95 million hectares in 2014. This represents a change of 5.3 and -1.5 percent for 1990 and 2014 in coastal Alaska, respectively. This discrepancy will be corrected in the 2016 submission. Forest C stocks do not include forest stocks in U.S. territories, Hawaii, a large portion of Alaska, or trees on non-forest land (e.g., urban trees, agroforestry systems). Wood product stocks include exports, even if the logs are processed in other countries, and exclude imports. Forest area estimates are based on interpolation and extrapolation of Inventory data as described in Smith et al. (2010) and in Annex 3.13. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding. Inventories are assumed to represent stocks as of January 1 of the Inventory year. Flux is the net annual change in stock. Thus, an estimate of flux for 2013 requires estimates of C stocks for 2013 and 2014.

Figure 6-4: Estimates of Net Annual Changes in C Stocks for Major C Pools

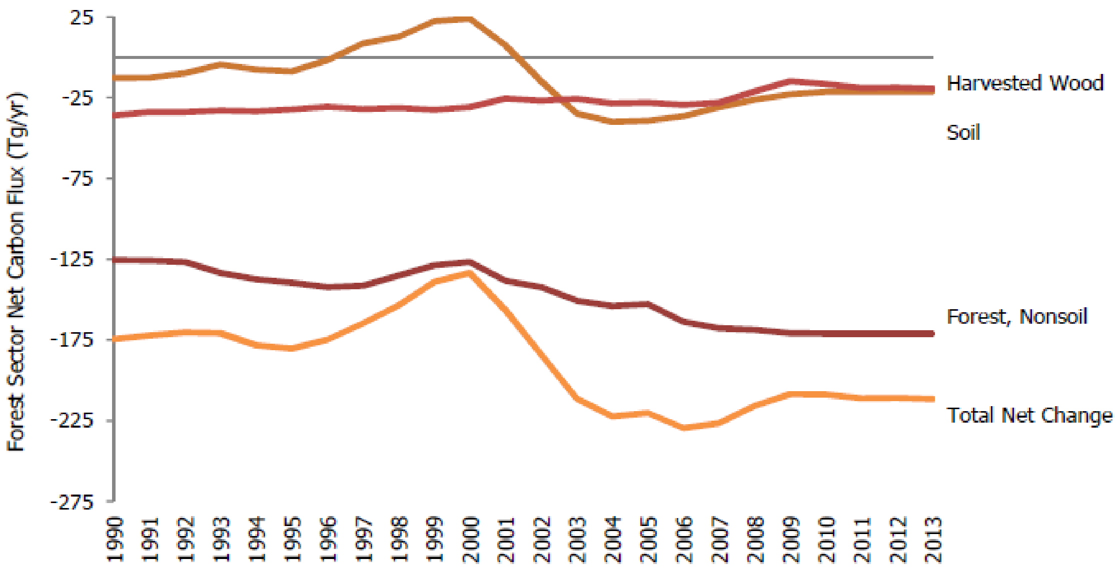


Figure 6-5: Forest Ecosystem C Density Imputed from Forest Inventory Plots, Conterminous United States, 2001–2009

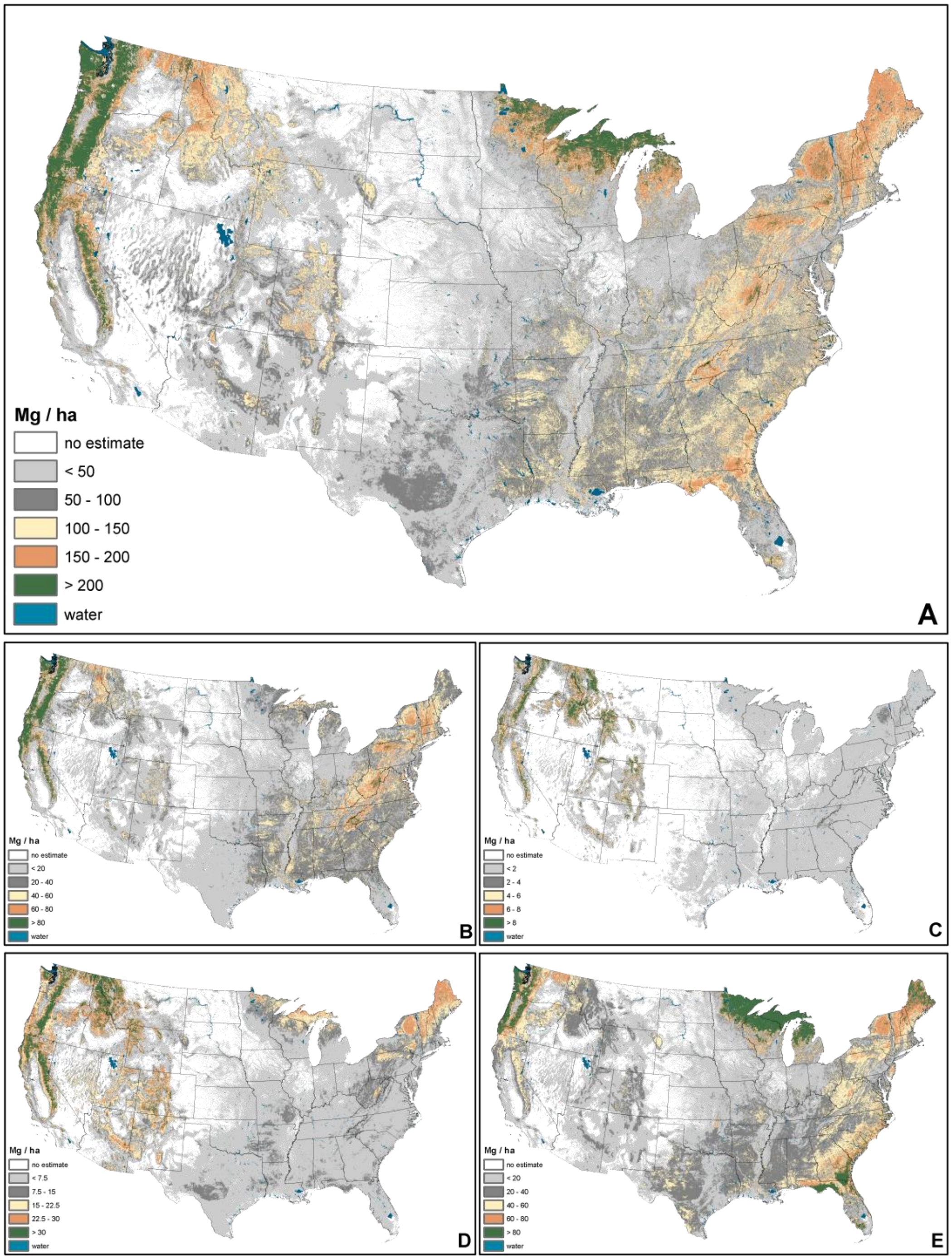


Figure 6-5 shows: (A) Total forest ecosystem C, (B) aboveground live trees, (C) standing dead trees, (D) litter, and (E) soil organic C (Wilson et al. 2013).

Box 6-3: CO_2 Emissions from Forest Fires

As stated previously, the forest inventory approach implicitly accounts for emissions due to disturbances such as forest fires, because only C remaining in the forest is estimated. Net C stock change is estimated by subtracting consecutive C stock estimates. A forest fire disturbance removes C from the forest. The inventory data on which net C stock estimates are based already reflect this C loss. Therefore, estimates of net annual changes in C stocks for U.S. forest land already account for CO_2 emissions from forest fires occurring in the lower 48 states as well as in the proportion of Alaska's managed forest land captured in this Inventory. Because it is of interest to quantify the magnitude of CO_2 emissions from fire disturbance, these estimates are highlighted here, using the full extent of available data. Non-CO_2 greenhouse gas emissions from forest fires are also quantified in a separate section below.

The IPCC (2003) methodology and IPCC (2006) default combustion factor for wildfire were employed to estimate CO_2 emissions from forest fires. See the explanation in Annex 3.13 for more details on the methodology used to estimate CO_2 emissions from forest fires. Carbon dioxide emissions for wildfires and prescribed fires in the lower 48 states and wildfires in Alaska in 2013 were estimated to be 77.9 MMT CO_2/yr. This amount is masked in the estimate of net annual forest C stock change for 2013 because this net estimate accounts for the amount sequestered minus any emissions.

Table 6-11: Estimates of CO_2 (MMT/yr) Emissions from Forest Fires for the Lower 48 States and Alaska

Year	CO_2 emitted from Wildfires in Lower 48 States (MMT/yr)	CO_2 emitted from Prescribed Fires in Lower 48 States (MMT/yr)	CO_2 emitted from Wildfires in Alaska (MMT/yr)	Total CO_2 emitted (MMT/yr)
1990	28.8	4.9	+	33.7
2005	95.8	14.8	+	110.7
2009	63.5	14.5	+	77.9
2010	49.5	13.9	+	63.4
2011	182.7	12.2	+	194.9
2012	197.7	11.5	+	209.1
2013	66.2	11.7	+	77.9

+ Does not exceed 0.05 MMT CO_2 Eq.

Note: These emissions have already been accounted for in the estimates of net annual changes in C stocks, which account for the amount sequestered minus any emissions.

Methodology and Data Sources

The methodology described herein is consistent with IPCC (2006). Forest ecosystem C stocks and net annual C stock change were determined according to stock-difference methods, which involved applying C estimation factors to forest inventory data and interpolating between successive inventory-based estimates of C stocks. Harvested wood C estimates were based on factors such as the allocation of wood to various primary and end-use products as well as half-life (the time at which half of the amount placed in use will have been discarded from use) and expected disposition (e.g., product pool, SWDS, combustion). An overview of the different methodologies and data sources used to estimate the C in forest ecosystems or harvested wood products is provided here. See Annex 3.13 for details and additional information related to the methods and data.

Forest Ecosystem Carbon from Forest Inventory

Forest ecosystem stock and flux estimates are based on the stock-difference method and calculations for all estimates are in units of C. Separate estimates were made for the five IPCC C storage pools described above. All estimates were based on data collected from the extensive array of permanent forest inventory plots and associated models (e.g., live tree belowground biomass) in the United States (USDA Forest Service 2013b, 2013c). Carbon conversion factors were applied at the disaggregated level of each inventory plot and then appropriately expanded to population estimates. A combination of tiers as outlined by IPCC (2006) were used. The Tier 3 biomass C estimates were calculated from forest inventory tree-level data. The Tier 2 dead organic and soil C estimates were obtained from empirical or theoretical models using the inventory data. All C conversion factors are specific to regions or individual states within the United States, which were further classified according to characteristic forest types within each region.

The first step in developing forest ecosystem estimates is to identify useful inventory data and resolve any inconsistencies among datasets. Forest inventory data were obtained from the FIA program (Frayer and Furnival 1999, USDA Forest Service 2014b). Inventories include data collected on permanent inventory plots on forest lands and were organized as separate datasets, each representing a complete inventory, or survey, of an individual state at a specified time. Many of the more recent annual inventories reported for states are represented as "moving window" averages, which means that a portion—but not all—of the previous year's inventory is updated each year (USDA Forest Service 2014d). Forest C calculations are organized according to these state surveys, and the frequency of surveys varies by state. All available datasets are identified for each state starting with pre-1990 data, and all unique surveys are identified for stock and change calculations. Since C stock change is based on differences between successive surveys within each state, accurate estimates of net C flux thus depend on consistent representation of forest land between these successive inventories. In order to achieve this consistency from 1990 to the present, states are sometimes subdivided into sub-state areas where the sum of sub-state inventories produces the best whole-state representation of C change as discussed in Smith et al. (2010).

The principal FIA datasets employed are freely available for download at USDA Forest Service (2014b) as the Forest Inventory and Analysis Database (FIADB) Version 6.0 (USDA Forest Service 2014c). However, to achieve consistent representation (spatial and temporal), three other general sources of past FIA data were included as necessary. First, older FIA plot- and tree-level data—not in the current FIADB format—are used if available. Second, Resources Planning Act Assessment (RPA) databases, which are periodic, plot-level only, summaries of state inventories, are used to provide the data at or before 1990. Finally, the Integrated Database (IDB), which is a compilation of periodic forest inventory data from the 1990s for California, Oregon, and Washington is used (Waddell and Hiserote 2005). These IDB data were identified by Heath et al. (2011) as the most appropriate non-FIADB sources for these states and are included in this Inventory. See USDA Forest Service (2014a) for information on current and older data as well as additional FIA Program features. A detailed list of the specific forest inventory data used in this Inventory is included in Annex 3.13.

Modifications to the use of some of the FIADB surveys or subsequent C conversions were initiated for this report. First, the most-recent FIA population summary (known as an evaluation within the FIADB) was incorporated into all states' stock-change calculations which stands in contrast to the approach in previous years where most of the newest evaluations were already in use, but if the majority of the underlying plots in the most recent population were also a part of the previous population (i.e., over 50 percent redundant plots) then the recent population was considered insufficiently unique and not used for calculation. Second, modifications were conducted in coastal Alaska for developing net annual change estimates (see Annex 3.13) and separating managed versus unmanaged forest lands in order to exclude C stock and stock-change on unmanaged forest land (IPCC 2006, Ogle et al. in preparation). This reduced the plots contributing to the Alaska forest C estimates by about 5 percent. A third modification to the use of the FIADB-defined forest land, introduced this year, was applied to identify plots on woodland forest types that do not meet the height requirement within the definition of forest land (Oswalt et al. 2014, Coulston et al. in preparation). These plots were identified as "other wooded lands" (i.e., not "forest" within the FIA forest inventory) and provided as C density information to the grasslands land-use category as the plots were not a complete inventory of the grassland land-use category in the United States. Finally, a new model estimating plot level C density of litter was developed and incorporated into the C budget (Domke et al. in preparation).

Forest C stocks were estimated from inventory data by a collection of conversion factors and models (Birdsey and Heath 1995, Birdsey and Heath 2001, Heath et al. 2003, Smith et al. 2004, Smith et al. 2006, Woodall et al. 2011a, Domke et al. 2011, Domke et al. 2012, Domke et al. in preparation), which have been formalized in an FIADB-to-C calculator (Smith et al. 2010). The conversion factors and model coefficients were categorized by region and forest type, and forest C stock estimates were calculated from application of these factors at the scale of FIA inventory plots. The results were estimates of C density (T C per hectare) for six forest ecosystem pools: Live trees, standing dead trees, understory vegetation, downed dead wood, forest floor, and soil organic matter. The six C pools used in the FIADB-to-C calculator were aggregated to the five C pools defined by IPCC (2006): Aboveground biomass, belowground biomass, dead wood, litter, and soil organic matter. The live-tree and understory C were pooled as biomass, and standing dead trees and downed dead wood were pooled as dead wood, in accordance with IPCC (2006).

Once plot-level C stocks were calculated as C densities on *Forest Land Remaining Forest Land* for the five IPCC (2006) reporting pools, the stocks were expanded to population estimates according to methods appropriate to the respective inventory data (for example, see Bechtold and Patterson (2005)). These expanded C stock estimates were summed to state or sub-state total C stocks. Annualized estimates of C stocks were developed by using available FIA inventory data and interpolating or extrapolating to assign a C stock to each year in the 1990 through 2014 time series. Flux, or net annual stock change, was estimated by calculating the difference in stocks between two successive years and applying the appropriate sign convention; net increases in ecosystem C were identified as negative flux. By convention, inventories were assigned to represent stocks as of January 1 of the inventory year; an estimate of flux for 1996 required estimates of C stocks for 1996 and 1997, for example. Additional discussion of the use of FIA inventory data and the C conversion process is in Annex 3.13.

Carbon in Biomass

Live tree C pools include aboveground and belowground (coarse root) biomass of live trees with diameter at diameter breast height (dbh) of at least 2.54 cm at 1.37 m above the forest floor. Separate estimates were made for above- and below-ground biomass components. If inventory plots included data on individual trees, tree C was based on Woodall et al. (2011a), which is also known as the component ratio method (CRM), and is a function of volume, species, and diameter. An additional component of foliage, which was not explicitly included in Woodall et al. (2011a), was added to each tree following the same CRM method. Some of the older forest inventory data in use for these estimates did not provide measurements of individual trees. Examples of these data include plots with incomplete or missing tree data or the RPA plot-level summaries. The C estimates for these plots were based on average densities (T C per hectare) obtained from plots of more recent surveys with similar stand characteristics and location. This applies to less than 5 percent of the forest land inventory-plot-to-C conversions within the 214 state-level surveys utilized here.

Understory vegetation is a minor component of biomass, which is defined as all biomass of undergrowth plants in a forest, including woody shrubs and trees less than 2.54 cm dbh. In the current Inventory, it was assumed that 10 percent of total understory C mass is belowground. Estimates of C density were based on information in Birdsey (1996) and biomass estimates from Jenkins et al. (2003). Understory frequently represented over 1 percent of C in biomass, but its contribution rarely exceeded 2 percent of the total.

Carbon in Dead Organic Matter

Dead organic matter was initially calculated as three separate pools—standing dead trees, downed dead wood, and litter—with C stocks estimated from sample data or from models. The standing dead tree C pools include aboveground and belowground (coarse root) mass and include trees of at least 12.7 cm dbh. Calculations followed the basic method applied to live trees (Woodall et al. 2011a) with additional modifications to account for decay and structural loss (Domke et al. 2011, Harmon et al. 2011). Similar to the situation with live tree data, some of the older forest inventory data did not provide sufficient data on standing dead trees to make accurate population-level estimates. The C estimates for these plots were based on average densities (T C per hectare) obtained from plots of more recent surveys with similar stand characteristics and location. This applied to less than 20 percent of the forest land inventory-plot-to-C conversions within the 214 state-level surveys utilized here. Downed dead wood estimates are based on measurement of a subset of FIA plots for downed dead wood (Domke et al. 2013, Woodall and Monleon 2008, Woodall et al. 2013). Downed dead wood is defined as pieces of dead wood greater than 7.5 cm diameter, at transect intersection, that are not attached to live or standing dead trees. This includes stumps and roots of harvested trees. To facilitate the downscaling of downed dead wood C estimates from the state-wide population estimates to individual plots, downed dead wood models specific to regions and forest types within each region are used. Litter C is the pool of organic C (also known as duff, humus, and fine woody debris) above the mineral soil and includes woody fragments with diameters of up to 7.5 cm. Estimates are based on Domke et al. (in preparation).

Carbon in Forest Soil

Soil organic C includes all organic material in soil to a depth of 1 meter but excludes the coarse roots of the biomass or dead wood pools. Estimates of SOC were based on the national STATSGO spatial database (USDA 1991), which includes region and soil type information. Soil organic C determination was based on the general approach described by Amichev and Galbraith (2004). Links to FIA inventory data were developed with the assistance of the USDA Forest Service FIA Geospatial Service Center by overlaying FIA forest inventory plots on the soil C map. This method produced mean SOC densities stratified by region and forest type group. It did not provide separate estimates for mineral or organic soils but instead weighted their contribution to the overall average based on the relative amount of each within forest land. Thus, forest SOC is a function of species and location, and net change also depends on these two factors as total forest area changes. In this respect, SOC provides a country-specific reference stock for 1990 through the present, but it does not reflect the effects of past land use.

Harvested Wood Carbon

Estimates of the HWP contribution to forest C sinks and emissions (hereafter called "HWP Contribution") were based on methods described in Skog (2008) using the WOODCARB II model. These methods are based on IPCC (2006) guidance for estimating HWP C. IPCC (2006) provides methods that allow for reporting of HWP Contribution using one of several different accounting approaches: Production, stock change and atmospheric flow, as well as a default method that assumes there is no change in HWP C stocks (see Annex 3.13 for more details about each approach). The United States used the production accounting approach to report HWP Contribution. Under the production approach, C in exported wood was estimated as if it remains in the United States, and C in imported wood was not included in inventory estimates. Though reported U.S. HWP estimates are based on the production approach, estimates resulting from use of the two alternative approaches, the stock change and atmospheric flow approaches, are also presented for comparison (see Annex 3.13). Annual estimates of change were calculated by tracking the additions to and removals from the pool of products held in end uses (i.e., products in use such as housing or publications) and the pool of products held in solid waste disposal sites (SWDS). Emissions from HWP associated with wood biomass energy are not included in this accounting—a net of zero sequestration and emissions as they are a part of energy accounting (see Chapter 3).

Solidwood products added to pools include lumber and panels. End-use categories for solidwood include single and multifamily housing, alteration and repair of housing, and other end-uses. There is one product category and one end-use category for paper. Additions to and removals from pools were tracked beginning in 1900, with the exception that additions of softwood lumber to housing began in 1800. Solidwood and paper product production and trade data were taken from USDA Forest Service and other sources (Hair and Ulrich 1963; Hair 1958; USDC Bureau of Census; 1976; Ulrich, 1985, 1989; Steer 1948; AF&PA 2006a 2006b; Howard 2003, 2007, forthcoming). Estimates for disposal of products reflected the change over time in the fraction of products discarded to SWDS (as opposed to burning or recycling) and the fraction of SWDS that were in sanitary landfills versus dumps.

There are five annual HWP variables that were used in varying combinations to estimate HWP Contribution using any one of the three main approaches listed above. These are:

(1A) annual change of C in wood and paper products in use in the United States,

(1B) annual change of C in wood and paper products in SWDS in the United States,

(2A) annual change of C in wood and paper products in use in the United States and other countries where the wood came from trees harvested in the United States,

(2B) annual change of C in wood and paper products in SWDS in the United States and other countries where the wood came from trees harvested in the United States,

(3) C in imports of wood, pulp, and paper to the United States,

(4) C in exports of wood, pulp and paper from the United States, and

(5) C in annual harvest of wood from forests in the United States.

The sum of variables 2A and 2B yielded the estimate for HWP Contribution under the production accounting approach. A key assumption for estimating these variables was that products exported from the United States and held in pools in other countries have the same half-lives for products in use, the same percentage of discarded products going to SWDS, and the same decay rates in SWDS as they would in the United States.

Uncertainty and Time Series Consistency

A quantitative uncertainty analysis placed bounds on current flux for forest ecosystems as well as C in harvested wood products through Monte Carlo Stochastic Simulation of the Methods described above and probabilistic sampling of C conversion factors and inventory data. See Annex 3.13 for additional information. The 2013 net annual change for forest C stocks was estimated to be between -972.9 and -575.9 MMT CO_2 Eq. at a 95 percent confidence level. This includes a range of -900.7 to -505.9 MMT CO_2 Eq. for forest ecosystems and -89.9 to -54.0 MMT CO_2 Eq. for HWP.

Table 6-12: Approach 2 Quantitative Uncertainty Estimates for Net CO_2 Flux from Forest Land Remaining Forest Land: Changes in Forest C Stocks (MMT CO_2 Eq. and Percent)

Source	Gas	2013 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Forest Ecosystem	CO_2	(704.9)	(900.7)	(505.9)	−27.8	28.2
Harvested Wood Products	CO_2	(70.8)	(89.9)	(54.0)	−27.0	23.7
Total Forest	**CO_2**	**(775.7)**	**(972.9)**	**(575.9)**	**−25.4**	**25.8**

Note: Parentheses indicate negative values or net sequestration.

[a] Range of flux estimates predicted by Monte Carlo stochastic simulation for a 95 percent confidence interval.

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2013. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

As discussed above, the FIA program has conducted consistent forest surveys based on extensive statistically-based sampling of most of the forest land in the conterminous United States, dating back to 1952. The FIA program includes numerous quality assurance and quality control (QA/QC) procedures, including calibration among field crews, duplicate surveys of some plots, and systematic checking of recorded data. Because of the statistically-based sampling, the large number of survey plots, and the quality of the data, the survey databases developed by the FIA program form a strong foundation for C stock estimates. Field sampling protocols, summary data, and detailed inventory databases are archived and are publicly available on the Internet (USDA Forest Service 2014d).

Many key calculations for estimating current forest C stocks based on FIA data were developed to fill data gaps in assessing forest C and have been in use for many years to produce national assessments of forest C stocks and stock changes (see additional discussion and citations in the Methodology section above and in Annex 3.13). General quality control procedures were used in performing calculations to estimate C stocks based on survey data. For example, the derived C datasets, which include inventory variables such as areas and volumes, were compared to standard inventory summaries such as the forest resource statistics of Smith et al. (2009) or selected population estimates generated from FIADB 6.0, which are available at an FIA internet site (USDA Forest Service 2014b). Agreement between the C datasets and the original inventories is important to verify accuracy of the data used. Finally, C stock estimates were compared with previous Inventory report estimates to ensure that any differences could be explained by either new data or revised calculation methods (see the “Recalculations” discussion, below).

Estimates of the HWP variables and the HWP contribution under the production accounting approach use data from U.S. Census and USDA Forest Service surveys of production and trade. Factors to convert wood and paper to units of C are based on estimates by industry and Forest Service published sources. The WOODCARB II model uses estimation methods suggested by IPCC (2006). Estimates of annual C change in solid wood and paper products in use were calibrated to meet two independent criteria. The first criterion is that the WOODCARB II model estimate of C in houses standing in 2001 needs to match an independent estimate of C in housing based on U.S. Census and USDA Forest Service survey data. Meeting the first criterion resulted in an estimated half-life of about 80 years for single family housing built in the 1920s, which is confirmed by other U.S. Census data on housing. The second criterion is that the WOODCARB II model estimate of wood and paper being discarded to SWDS needs to match EPA estimates of discards each year over the period 1990 to 2000 (EPA 2006). These criteria help reduce uncertainty in estimates of annual change in C in products in use in the United States and, to a lesser degree, reduce uncertainty in estimates of annual change in C in products made from wood harvested in the United States. In addition, WOODCARB II landfill decay rates have been validated by ensuring that estimates of CH_4 emissions from landfills based on EPA (2006) data are reasonable in comparison to CH_4 estimates based on WOODCARB II landfill decay rates.

Recalculations Discussion

Forest ecosystem stock and stock-change estimates differ from the previous Inventory (EPA 2014) principally due to some changes in data and methods (see discussion above in Methodology and in Annex 3.13). The net effect of the modifications was to slightly reduce net C uptake (i.e., lower sequestration) and C stocks from 1990 to the present. The influence of the individual modifications on stock and stock-change varied considerably; these were evaluated to identify the relative sensitivity of totals to each. That is, the analysis identified where the estimates (as in Tables Table 6-8 through Table 6-10) were most affected by the revised methods incorporated with this report. First, the collective effects of selecting FIA population estimates and updates to the annual forest inventories for many states had the effect of decreasing sequestration in early years while increasing after 2005 and had the greatest effect on determining overall stock-change estimates for 2006 and 2007, but otherwise this modification was a minor influence. Second, the application of a new managed land definition as part of the land representation analysis (see Section 6.1) and the subsequent decrease in managed forest lands along coastal Alaska affected that individual state's estimates but had minimal effect on C stock estimates for the United States as a whole. Third, the reallocation of selected woodlands from forest land (i.e., these "other wooded lands" were then classified as grasslands) had the greatest effect on annualized estimates of forest area throughout the time series. In addition, the removal of these lands from forest had the greatest effect on total forest stock-change through the early 1990s, yet the reclassification did tend to decrease sequestration throughout the entire time series. Finally, the revised litter C estimates generally had a lower influence on stock-change relative to the woodland modification. However, the revised litter estimates increased sequestration through the 1990s but decreased sequestration over more recent years. In addition, the change in estimated litter C had the greatest effect on forest ecosystem stocks throughout the time period.

The estimate of net annual change in HWP C stock and total C stock in HWP were revised upward by small amounts. The increase in total net annual additions compared to estimates published in 2013 was 2 to 3 percent for 2010 through 2012. This increase was mostly due to changes in the amount of pulpwood used for paper and composite panel products back to 2003. All the adjustments were made as a result of corrections in the database of forest products statistics used to prepare the estimates (Howard forthcoming).

Planned Improvements

Reliable estimates of forest C across the diverse ecosystems/industries of the United States require a high level of investment in both annual monitoring and associated analytical techniques. Development of improved monitoring/reporting techniques is a continuous process that occurs simultaneously with annual Inventory submissions. Planned improvements can be broadly assigned to the following categories: Pool estimation techniques, land use and land-use change, and field inventories.

In an effort to reduce the uncertainty associated with the estimation of individual forest C pools, the empirical data and associated models for each pool are being evaluated for potential improvement (Woodall 2012). In the 1990 through 2010 Inventory report, the approach to tree volume/biomass estimation was evaluated and refined (Domke et al. 2012). In the 1990 through 2011 Inventory report, the standing dead tree C model was replaced with a nationwide inventory and associated empirical estimation techniques (Woodall et al. 2012, Domke et al. 2011, Harmon et al. 2011). In the 1990 through 2012 Inventory report the downed dead tree C model was refined by incorporation of a national field inventory of downed dead wood (Woodall et al. 2013, Domke et al. 2013). In the current Inventory report, the litter C density model was refined with a nearly nationwide field inventory (Domke et al. in preparation). The exact timing of future pool estimation refinements is dependent on the completion of current research efforts. Research is underway to use a national inventory of SOC (Woodall et al. 2011b) to refine the estimation of this pool. It is expected that improvements to SOC estimation will be incorporated into the 1990 through 2015 Inventory report. Components of other pools, such as C in belowground biomass (Russell et al. in preparation) and understory vegetation (Russell et al. in press), are being explored but may require additional investment in field inventories before improvements can be realized with Inventory submissions.

Despite the continuing accumulation of new data within the consistent nationwide field inventory of forests that is measured annually, additional research advances are needed to attain a complete, consistent, and accurate time series of annual land-use and land-use change matrices from 1990 to the present report year. Lines of research have been initiated to more fully examine land-use change within the FIA inventory system (see Figure 6-3; Coulston et al. in review, Wear and Coulston 2014) and bring together disparate sets of land-use information (e.g., forest versus croplands) that rely on remotely sensed imagery from the 1980s to the present (NASA CMS 2013). These lines of research are expected to require at least a few years for completion with subsequent time needed for application to future Inventory submissions.

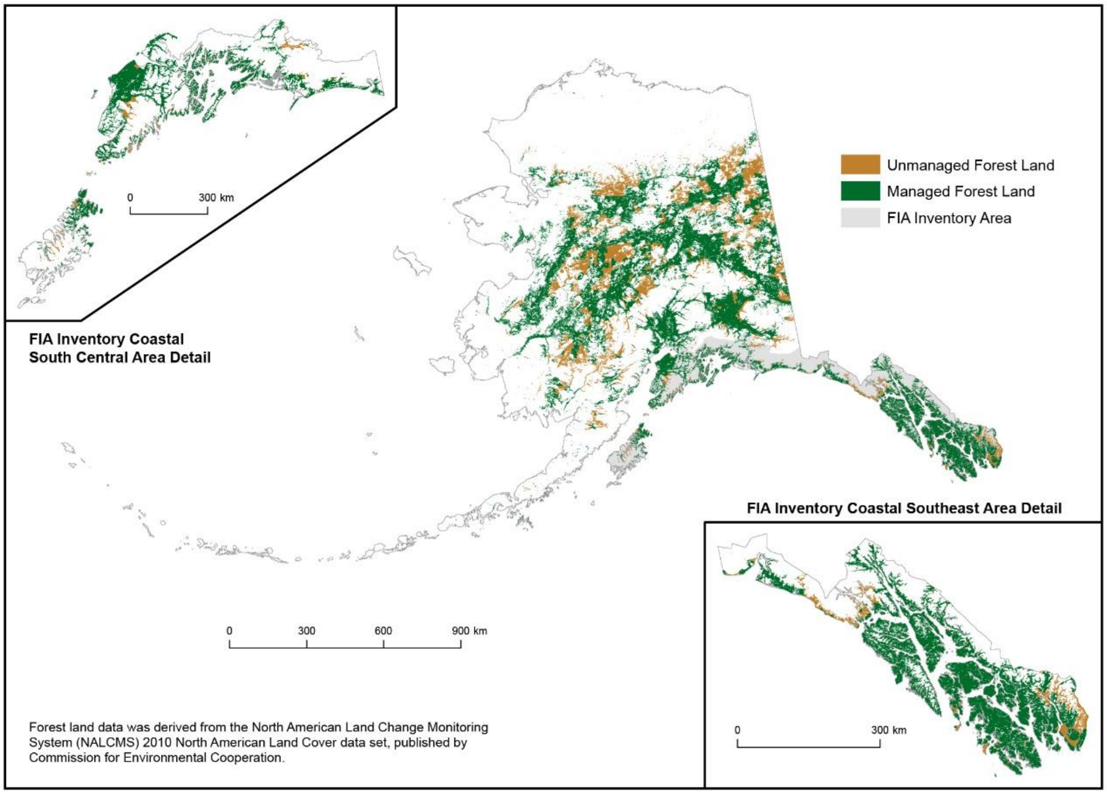
The foundation of forest C accounting is the annual forest inventory system. The ongoing annual surveys by the FIA Program are expected to improve the accuracy and precision of forest C estimates as new state surveys become available (USDA Forest Service 2013b), particularly in western states. Hawaii and U.S. territories will be included when appropriate forest C data are available (as of July 21, 2014, Hawaii is not yet reporting any data from the annualized sampling design). In addition, the more intensive sampling of fine woody debris, litter, and SOC on a subset of FIA plots continues and will substantially improve resolution of C pools (i.e., greater sample intensity; Westfall et al. 2013) this information becomes available (Woodall et al. 2011b). Increased sample intensity of some C pools and using annualized sampling data as it becomes available for those states currently not reporting are planned for future submissions. The USDA Forest Service FIA Program's forest and wooded land inventories extend beyond the forest land-use (e.g., woodlands and urban areas), and Inventory-relevant information for these lands will likely become increasingly available in coming years.

Towards an Accounting of Managed Forest Carbon in Interior Alaska

Given the remote nature and vast expanse of forest across the state of Alaska, consistent inventories of all Alaskan forest land have never been conducted. Figure 6-6 compares the vast expanse of Alaska to countries in Europe, which in large part explains the lack of a consistent forest inventory and provides an indication of the extent of any effort to include an area of this magnitude using the existing forest inventories for the United States. Starting in the 1990s, a forest inventory of south central and southeastern coastal (SCSE) Alaska was initiated following the same approach applied in the conterminous United States (see Figure 6-7).

Figure 6-6: The Size of Alaska Compared to European Countries

Figure 6-7: Delineations between Forest, Non-forest, Managed Land, and Inventoried Areas of Alaska



Establishment and data collection on these plots began in 1995 with the current inventory nearing completion of a full re-measurement (i.e., one cycle of periodic inventory represented by the 2003 data and 90 percent of an annual inventory cycle represented by the 2012 data). Forest C estimates for SCSE Alaska were first included in the Inventory in 2008. The managed forest land in SCSE Alaska has been the only contribution to the Inventory since 2008 owing to the lack of a consistent inventory across the much larger interior portion of Alaska that generally includes less productive forest lands.

Recognizing the need to inventory interior Alaskan forests for the Inventory and resource management, research is being conducted towards these ends:

- A spatial model delineating managed and unmanaged lands for Alaska was developed in part to better align greenhouse gas reporting with managed lands for Alaskan forests (Ogle et al. in preparation). In contrast to Alaska, all forest lands in the conterminous 48 states are considered managed for purposes of greenhouse gas reporting. The spatial model of managed lands for Alaska is applied to both the preliminary assessment of interior Alaskan forest C provided here and the reported C of SCSE Alaska in order to align with the practice of reporting of forest C on managed lands per IPCC (2006) *Good Practice Guidelines*.
- Research continues to better appraise the forest C stocks and their associated dynamics across the Alaskan landscape that rely on remotely sensed imagery and limited in situ measurements. Based on this emerging work the amount of managed forest land and ranges of C stocks will be estimated. This current work (McGuire et al. in preparation, Genet et al. in preparation, Saatchi et al. in preparation) has identified 46–49 million hectares of managed forestland in interior Alaska. This represents 68 percent of total interior forest land. Live biomass (e.g., vegetation) C stocks are estimated to range between 1,600 and 2,100 MMT C and non-live biomass (e.g., soils, deadwood, litter) is estimated to range between 6,100 and 13,000 MMT C), all with concomitant high levels of uncertainty.

- A joint USDA Forest Service-National Aeronautics and Space Administration research effort was conducted in interior Alaska during the summer of 2014 where high-resolution airborne scanning laser, hyperspectral, and thermal imagery were collected in a sampling mode over the entire Tanana valley (135,000 km^2). These remotely-sensed data will be combined with a limited number of in situ plot measurements (100 FIA plots collected within the Tanana Valley State Forest and Tetlin National Wildlife Refuge) to explore potential application across interior Alaska (NASA CMS 2014). Results from this research study are expected within a few years.

As preliminary research results suggest that the managed forest C stock may be upwards of 15,000 MMT C or 37 percent of the United States' managed forest C stock in the current Inventory, care must be given to vet all emerging research especially in regards to stock change. It is hoped that the managed forest land base in interior Alaska might be included in future Inventories if: (a) adequate funding resources become available, and (b) research into combining remotely sensed technologies with in situ measurements (especially of non-vegetation pools) is a success.

Non-CO_2 Emissions from Forest Fires

Emissions of non-CO_2 gases from forest fires were estimated using the default IPCC (2003) methodology incorporating default IPCC (2006) emissions factors and combustion factor for wildfires. Emissions from this source in 2013 were estimated to be 5.8 MMT CO_2 Eq. of CH_4 and 3.8 MMT CO_2 Eq. of N_2O, as shown in Table 6-13 and Table 6-14. The estimates of non-CO_2 emissions from forest fires account for wildfires in the lower 48 states and Alaska as well as prescribed fires in the lower 48 states.

Table 6-13: Estimated Non-CO_2 Emissions from Forest Fires (MMT CO_2 Eq.) for U.S. Forests

Gas	1990		2005		2009	2010	2011	2012	2013
CH_4	2.5		8.3		5.8	4.7	14.6	15.7	5.8
N_2O	1.7		5.5		3.8	3.1	9.6	10.3	3.8
Total	**4.2**		**13.8**		**9.7**	**7.9**	**24.2**	**26.0**	**9.7**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
Note: Calculated based on C emission estimates in *Changes in Forest Carbon Stocks* and default factors in IPCC (2006).

Table 6-14: Estimated Non-CO_2 Emissions from Forest Fires (kt) for U.S. Forests

Gas	1990		2005		2009	2010	2011	2012	2013
CH_4	101		332		233	190	584	626	233
N_2O	6		18		13	11	32	35	13

Note: Calculated based on C emission estimates in *Changes in Forest Carbon Stocks* and default factors in IPCC (2006).

Methodology

The IPCC (2003) Tier 2 default methodology was used to calculate C and CO_2 emissions from forest fires. However, more up-to-date default emission factors from IPCC (2006) were converted into gas-specific emission ratios and incorporated into the methodology to calculate non-CO_2 emissions from C emissions. Estimates of CH_4 and N_2O emissions were calculated by multiplying the total estimated CO_2 emitted from forest burned by the gas-specific emissions ratios. CO_2 emissions were estimated by multiplying total C emitted (Table 6-15) by the C to CO_2 conversion factor of 44/12 and by 92.8 percent, which is the estimated proportion of C emitted as CO_2 (Smith 2008a). The equations used to calculate CH_4 and N_2O emissions were:

$$\text{CH}_4 \text{ Emissions} = (\text{C released}) \times 92.8\% \times (44/12) \times (\text{CH}_4 \text{ to CO}_2 \text{ emission ratio})$$

$$\text{N}_2\text{O Emissions} = (\text{C released}) \times 92.8\% \times (44/12) \times (\text{N}_2\text{O to CO}_2 \text{ emission ratio})$$

Where CH_4 to CO_2 emission ratio is 0.003 and N_2O to CO_2 emission ratio is 0.0002. See the explanation in Annex 3.13 for more details on the CH_4 and N_2O to CO_2 emission ratios.

Estimates for C emitted from forest fires are the same estimates used to generate estimates of CO_2 presented earlier in Box 6-3. Estimates for C emitted include emissions from wildfires in both Alaska and the lower 48 states as well as emissions from prescribed fires in the lower 48 states only (based on expert judgment that prescribed fires only occur in the lower 48 states) (Smith 2008a). The IPCC (2006) default combustion factor of 0.45 for "all 'other' temperate forests" was applied in estimating C emitted from both wildfires and prescribed fires. See the explanation in Annex 3.13 for more details on the methodology used to estimate C emitted from forest fires.

Table 6-15: Estimated C Released from Forest Fires for U.S. Forests (MMT/yr)

Year	C Emitted (MMT/yr)
1990	9.9
2005	32.5
2009	22.9
2010	18.6
2011	57.3
2012	61.5
2013	22.9

Uncertainty and Time-Series Consistency

Non-CO_2 gases emitted from forest fires depend on several variables, including: forest area for Alaska and the lower 48 states; average C densities for wildfires in Alaska, wildfires in the lower 48 states, and prescribed fires in the lower 48 states; emission ratios; and combustion factor values (proportion of biomass consumed by fire). To quantify the uncertainties for emissions from forest fires, a Monte Carlo (Approach 2) uncertainty analysis was performed using information about the uncertainty surrounding each of these variables. The results of the Approach 2 quantitative uncertainty analysis are summarized in Table 6-16.

Table 6-16: Approach 2 Quantitative Uncertainty Estimates of Non-CO_2 Emissions from Forest Fires in *Forest Land Remaining Forest Land* (MMT CO_2 Eq. and Percent)

Source	Gas	2013 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Non-CO_2 Emissions from Forest Fires	CH_4	5.8	1.1	15.2	−80%	+161%
Non-CO_2 Emissions from Forest Fires	N_2O	3.8	1.1	9.2	−71%	+139%

[a] Range of flux estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2013. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

Tier 1 and Tier 2 QA/QC activities were conducted consistent with the U.S. QA/QC plan. Source-specific quality control measures for forest fires included checking input data, documentation, and calculations to ensure data were properly handled through the inventory process. The QA/QC analysis did not reveal any inaccuracies or incorrect input values.

Recalculations Discussion

The current Inventory estimates for 1990 through 2013 were developed according to the methodology used in the previous Inventory report. However, the FIADB updates discussed in *Changes in Forest Carbon Stocks* affected forest C stocks, C density of litter, and total forest area, including the forest area estimates for coastal Alaska, all of which are used to calculate emissions estimates from forest fires. As a result of the FIADB updates, total non-CO_2 emissions from forest fires decreased by an average of 14 percent relative to emission estimates in the previous Inventory report.

For the current Inventory, emission estimates have been revised to reflect the GWPs provided in the *IPCC Fourth Assessment Report* (AR4) (IPCC 2007). AR4 GWP values differ slightly from those presented in the *IPCC Second Assessment Report* (SAR) (IPCC 1996) (used in the previous inventories) which results in time-series recalculations for most inventory sources. Under the most recent reporting guidelines (UNFCCC 2014), countries are required to report using the AR4 GWPs, which reflect an updated understanding of the atmospheric properties of each greenhouse gas. The GWP of CH_4 has increased, leading to an overall increase in CO_2-equivalent emissions from CH_4. The GWP of N_2O has decreased, leading to a decrease in CO_2-equivalent emissions for N_2O. The AR4 GWPs have been applied across the entire time series for consistency. For more information please see the Recalculations and Improvements Chapter.

The combined effect of the FIADB updates and AR4 GWP values resulted in an average 7 percent decrease in total non-CO_2 emissions from wildfires and prescribed fires over the 1990 to 2012 time series.

Planned Improvements

The default combustion factor of 0.45 from IPCC (2006) was applied in estimating C emitted from both wildfires and prescribed fires. Additional research into the availability of a combustion factor specific to prescribed fires is being conducted.

Another area of improvement is to evaluate other methods of obtaining data on forest area burned by replacing ratios of forest land to land under wildland protection with Monitoring Trends in Burn Severity (MTBS) burn area data. MTBS data is available from 1984 through a portion of 2013. MTBS burn area data could be used to develop the national area burned and resulting CO_2 and non-CO_2 emissions. Additional research is required to determine appropriate uncertainty inputs for national area burned data derived from MTBS data.

N_2O Fluxes from Forest Soils (IPCC Source Category 4A1)

Of the synthetic nitrogen (N) fertilizers applied to soils in the United States, no more than one percent is applied to forest soils. Application rates are similar to those occurring on cropland soils, but in any given year, only a small proportion of total forested land receives N fertilizer. This is because forests are typically fertilized only twice during their approximately 40-year growth cycle (once at planting and once midway through their life cycle). Thus, while the rate of N fertilizer application for the area of forests that receives N fertilizer in any given year is relatively high, the annual application rate is quite low over the entire forestland area.

N additions to soils result in direct and indirect N_2O emissions. Direct emissions occur on-site due to the N additions. Indirect emissions result from fertilizer N that is transformed and transported to another location in a form other than N_2O (NH_3 and NO_x volatilization, NO_3 leaching and runoff), and later converted into N_2O at the off-site location. The indirect emissions are assigned to forest land because the management activity leading to the emissions occurred in forest land.

Direct N_2O emissions from forest soils in 2013 were 0.3 MMT CO_2 Eq. (1 kt), and the indirect emission were 0.1 MMT CO_2 Eq. (0.4 kt). Total emissions for 2013 were 0.5 MMT CO_2 Eq. (2 kt) and have increased by 455 percent from 1990 to 2013. Increasing emissions over the time series is a result of greater area of N fertilized pine plantations in the southeastern United States and Douglas-fir timberland in western Washington and Oregon. Total forest soil N_2O emissions are summarized in Table 6-17.

Table 6-17: N_2O Fluxes from Soils in *Forest Land Remaining Forest Land* (MMT CO_2 Eq. and kt N_2O)

	1990		2005		2009	2010	2011	2012	2013
Direct N_2O Fluxes from Soils									
MMT CO_2 Eq.	0.1		0.3		0.3	0.3	0.3	0.3	0.3
kt N_2O	+		1		1	1	1	1	1
Indirect N_2O Fluxes from Soils									
MMT CO_2 Eq.	+		0.1		0.1	0.1	0.1	0.1	0.1

kt N_2O	+		+		+	+	+	+	+
Total									
MMT CO_2 Eq.	**0.1**		**0.5**		**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
kt N_2O	**+**		**2**		**2**	**2**	**2**	**2**	**2**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
+ Does not exceed 0.05 MMT CO_2 Eq. or 0.5 kt.

Methodology

The IPCC Tier 1 approach was used to estimate N_2O from soils within *Forest Land Remaining Forest Land*. According to U.S. Forest Service statistics for 1996 (USDA Forest Service 2001), approximately 75 percent of trees planted were for timber, and about 60 percent of national total harvested forest area is in the southeastern United States. Although southeastern pine plantations represent the majority of fertilized forests in the United States, this Inventory also accounted for N fertilizer application to commercial Douglas-fir stands in western Oregon and Washington. For the Southeast, estimates of direct N_2O emissions from fertilizer applications to forests were based on the area of pine plantations receiving fertilizer in the southeastern United States and estimated application rates (Albaugh et al. 2007; Fox et al. 2007). Not accounting for fertilizer applied to non-pine plantations is justified because fertilization is routine for pine forests but rare for hardwoods (Binkley et al. 1995). For each year, the area of pine receiving N fertilizer was multiplied by the weighted average of the reported range of N fertilization rates (121 lbs. N per acre). Area data for pine plantations receiving fertilizer in the Southeast were not available for 2005-2013, so data from 2004 were used for these years. For commercial forests in Oregon and Washington, only fertilizer applied to Douglas-fir was accounted for, because the vast majority (approximately 95 percent) of the total fertilizer applied to forests in this region is applied to Douglas-fir (Briggs 2007). Estimates of total Douglas-fir area and the portion of fertilized area were multiplied to obtain annual area estimates of fertilized Douglas-fir stands. Similar to the Southeast, data were not available for 2005 through 2013, so data from 2004 were used for these years. The annual area estimates were multiplied by the typical rate used in this region (200 lbs. N per acre) to estimate total N applied (Briggs 2007), and the total N applied to forests was multiplied by the IPCC (2006) default emission factor of 1 percent to estimate direct N_2O emissions.

For indirect emissions, the volatilization and leaching/runoff N fractions for forest land were calculated using the IPCC default factors of 10 percent and 30 percent, respectively. The amount of N volatilized was multiplied by the IPCC default factor of 1 percent for the portion of volatilized N that is converted to N_2O off-site. The amount of N leached/runoff was multiplied by the IPCC default factor of 0.075 percent for the portion of leached/runoff N that is converted to N_2O off-site The resulting estimates were summed to obtain total indirect emissions.

Uncertainty and Time-Series Consistency

The amount of N_2O emitted from forests depends not only on N inputs and fertilized area, but also on a large number of variables, including organic C availability, oxygen gas partial pressure, soil moisture content, pH, temperature, and tree planting/harvesting cycles. The effect of the combined interaction of these variables on N_2O flux is complex and highly uncertain. IPCC (2006) does not incorporate any of these variables into the default methodology, except variation in estimated fertilizer application rates and estimated areas of forested land receiving N fertilizer. All forest soils are treated equivalently under this methodology. Furthermore, only synthetic N fertilizers are captured, so applications of organic N fertilizers are not estimated. However, the total quantity of organic N inputs to soils is included in the *Agricultural Soil Management* and *Settlements Remaining Settlements* sections.

Uncertainties exist in the fertilization rates, annual area of forest lands receiving fertilizer, and the emission factors. Fertilization rates were assigned a default level[30] of uncertainty at ±50 percent, and area receiving fertilizer was assigned a ±20 percent according to expert knowledge (Binkley 2004). The uncertainty ranges around the 2005 activity data and emission factor input variables were directly applied to the 2013 emissions estimates. IPCC (2006) provided estimates for the uncertainty associated with direct and indirect N_2O emission factor for synthetic N fertilizer application to soils.

[30] Uncertainty is unknown for the fertilization rates so a conservative value of ±50 percent was used in the analysis.

Quantitative uncertainty of this source category was estimated using simple error propagation methods (IPCC 2006). The results of the quantitative uncertainty analysis are summarized in Table 6-18. Direct N_2O fluxes from soils were estimated to be between 0.1 and 1.1 MMT CO_2 Eq. at a 95 percent confidence level. This indicates a range of 59 percent below and 211 percent above the 2013 emission estimate of 0.3 MMT CO_2 Eq. Indirect N_2O emissions in 2013 were between 0.02 and 0.4 MMT CO_2 Eq., ranging from 86 percent below to 238 percent above the 2013 emission estimate of 0.11 MMT CO_2 Eq.

Table 6-18: Quantitative Uncertainty Estimates of N_2O Fluxes from Soils in *Forest Land Remaining Forest Land* (MMT CO_2 Eq. and Percent)

Source	Gas	2013 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate (MMT CO_2 Eq.)		(%)	
Forest Land Remaining Forest Land			**Lower Bound**	**Upper Bound**	**Lower Bound**	**Upper Bound**
Direct N_2O Fluxes from Soils	N_2O	0.3	0.1	1.1	-59%	+211%
Indirect N_2O Fluxes from Soils	N_2O	0.1	0.0	0.4	-86%	+238%

Note: These estimates include direct and indirect N_2O emissions from N fertilizer additions to both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2013. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

The spreadsheet tab containing fertilizer applied to forests and calculations for N_2O and uncertainty ranges were checked and corrected. Linkage errors in the uncertainty calculation for 2013 were found and corrected. The reported emissions in the NIR were also adjusted accordingly.

Recalculations Discussion

Indirect emissions from forest land were previously reported in *Agricultural Soil Management*, but are now included in this source category. Including indirect emissions resulted in a 27 percent increase.

Planned Improvements

Additional data will be compiled to update estimates of forest areas receiving N fertilizer as new reports are made available. Another improvement is to further disaggregate emissions by state for southeastern pine plantations and northwestern Douglas-fir forests to estimate soil N_2O emission. This improvement is contingent on the availability of state-level N fertilization data for forest land.

6.3 Land Converted to Forest Land (IPCC Source Category 4A2)

Land-use change is constantly occurring, and areas under a number of differing land-use types are converted to forest each year, just as forest land is converted to other uses. While the magnitude of these changes is known (see Table 6-5), research is ongoing to track C across *Forest Land Remaining Forest Land* and *Land Converted to Forest Land* areas. Until such time that reliable and comprehensive estimates of C across these land use and land-use change categories can be produced, it is not possible to separate CO_2 or N_2O fluxes on *Land Converted to Forest Land* from fluxes on *Forest Land Remaining Forest Land* at this time.

6.4 Cropland Remaining Cropland (IPCC Source Category 4B1)

Mineral and Organic Soil Carbon Stock Changes

Carbon (C) in cropland ecosystems occurs in biomass, dead biomass, and soils. However, C storage in biomass and dead organic matter is relatively ephemeral, with the exception of C stored in perennial woody crop biomass, such as citrus groves and apple orchards. Within soils, C is found in organic and inorganic forms of C, but soil organic C (SOC) is the main source and sink for atmospheric CO_2 in most soils. IPCC (2006) recommends reporting changes in SOC stocks due to agricultural land-use and management activities on both mineral and organic soils.[31]

Well-drained mineral soils typically contain from 1 to 6 percent organic C by weight, whereas mineral soils with high water tables for substantial periods during the year may contain significantly more C (NRCS 1999). Conversion of mineral soils from their native state to agricultural land uses can cause up to half of the SOC to be lost to the atmosphere due to enhanced microbial decomposition. The rate and ultimate magnitude of C loss depends on subsequent management practices, climate and soil type (Ogle et al. 2005). Agricultural practices, such as clearing, drainage, tillage, planting, grazing, crop residue management, fertilization, and flooding, can modify both organic matter inputs and decomposition, and thereby result in a net flux of C to or from the soil C pool (Parton et al. 1987, Paustian et al. 1997a, Conant et al. 2001, Ogle et al. 2005). Eventually, the soil can reach a new equilibrium that reflects a balance between C inputs (e.g., decayed plant matter, roots, and organic amendments such as manure and crop residues) and C loss through microbial decomposition of organic matter (Paustian et al. 1997b).

Organic soils, also referred to as histosols, include all soils with more than 12 to 20 percent organic C by weight, depending on clay content (NRCS 1999, Brady and Weil 1999). The organic layer of these soils can be very deep (i.e., several meters), and form under inundated conditions that results in minimal decomposition of plant residues. When organic soils are prepared for crop production, they are drained and tilled, leading to aeration of the soil that accelerates both the decomposition rate and CO_2 emissions. Due to the depth and richness of the organic layers, C loss from drained organic soils can continue over long periods of time, which varies depending on climate and composition (i.e., decomposability) of the organic matter (Armentano and Menges 1986). Due to deeper drainage and more intensive management practices, the use of organic soils for annual crop production leads to higher C loss rates than drainage of organic soils in grassland or forests (IPCC 2006).

Cropland Remaining Cropland includes all cropland in an Inventory year that has been used as cropland for the previous 20 years according to the 2007 USDA National Resources Inventory (NRI) land-use survey (USDA-NRCS 2009).[32] The inventory includes all privately-owned croplands in the conterminous United States and Hawaii, but does not include the 1 to 1.5 million hectares of *Cropland Remaining Cropland* (less than 1 percent of the total cropland area in the United States) on federal lands between 1990 and 2013. In addition, approximately 28,700 hectares of cropland in Alaska are not included in this Inventory. This leads to a discrepancy between the total amount of managed area in *Cropland Remaining Cropland* (see Section 6.1) and the cropland area included in the Inventory. Improvements are underway to include croplands in Alaska and federal lands as part of future C inventories.

CO_2 emissions and removals[33] due to changes in mineral soil C stocks are estimated using a Tier 3 approach for the majority of annual crops (Ogle et al. 2010). A Tier 2 IPCC method is used for the remaining crops not included in the Tier 3 method (i.e., vegetables, tobacco, perennial/horticultural crops, and rice) (Ogle et al. 2003, 2006). In addition, a Tier 2 method is used for very gravelly, cobbly, or shaley soils (i.e., classified as soils that have greater than 35 percent of soil volume comprised of gravel, cobbles, or shale) and for additional changes in mineral soil C

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[31] CO_2 emissions associated with liming are also estimated but are included in a separate section of the report.

[32] NRI points were classified according to land-use history records starting in 1982 when the NRI survey began, and consequently the classifications were based on less than 20 years from 1990 to 2001.

[33] Note that removals occur through uptake of CO_2 into crop and forage biomass that is later incorporated into soil C pools.

stocks that were not addressed with the Tier 3 approach (i.e., change in C stocks after 2007 due to Conservation Reserve Program enrollment). Emissions from organic soils are estimated using a Tier 2 IPCC method.

Land-use and land management of mineral soils was the largest contributor to total net C stock change, especially in the early part of the time series (see Table 6-19 and Table 6-20). (Note: Estimates after 2007 are based on NRI data from 2007 and therefore do not fully reflect changes occurring in the latter part of the time series). In 2013, mineral soils were estimated to remove 45.6 MMT CO_2 Eq. (12.4 MMT C). This rate of C storage in mineral soils represented about a 49 percent decrease in the rate since the initial reporting year of 1990. Emissions from organic soils were 22.1 MMT CO_2 Eq. (6.0 MMT C) in 2013, which is an 8 percent decrease compared to 1990. In total, United States agricultural soils in *Cropland Remaining Cropland* sequestered approximately 23.4 MMT CO_2 Eq. (6.4 MMT C) in 2013.

Table 6-19: Net CO_2 Flux from Soil C Stock Changes in *Cropland Remaining Cropland* (MMT CO_2 Eq.)

Soil Type	1990		2005		2009	2010	2011	2012	2013
Mineral Soils	(89.2)		(50.4)		(49.6)	(48.0)	(47.9)	(47.1)	(45.6)
Organic Soils	24.0		22.4		22.1	22.1	22.1	22.1	22.1
Total Net Flux	**(65.2)**		**(28.0)**		**(27.5)**	**(25.9)**	**(25.8)**	**(25.0)**	**(23.4)**

Note: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.
Note: Estimates after 2007 are based on NRI data from 2007 and therefore may not fully reflect changes occurring in the latter part of the time series

Table 6-20: Net CO_2 Flux from Soil C Stock Changes in *Cropland Remaining Cropland* (MMT C)

Soil Type	1990		2005		2009	2010	2011	2012	2013
Mineral Soils	(24.3)		(13.8)		(13.5)	(13.1)	(13.1)	(12.9)	(12.4)
Organic Soils	6.5		6.1		6.0	6.0	6.0	6.0	6.0
Total Net Flux	**(17.8)**		**(7.6)**		**(7.5)**	**(7.1)**	**(7.0)**	**(6.8)**	**(6.4)**

Note: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.
Note: Estimates after 2007 are based on NRI data from 2007 and therefore may not fully reflect changes occurring in the latter part of the time series

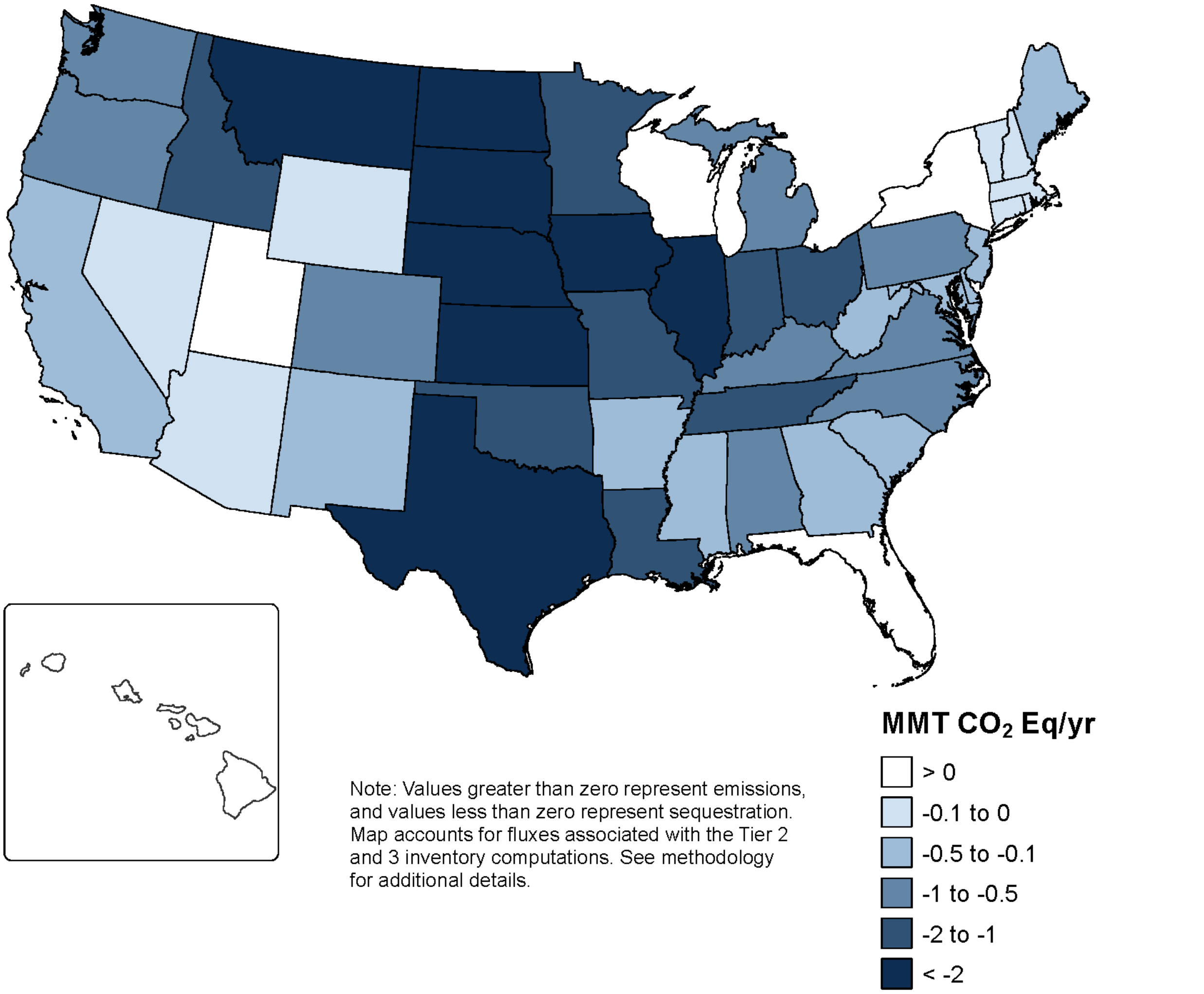
The major cause of the reduction in soil C accumulation over the time series (i.e., 2013 is 49 percent less than 1990) is the decline in annual cropland enrolled in the Conservation Reserve Program (CRP)[34] which was initiated in 1985 (Jones et al., in prep). For example, over 2 million hectares of land in the CRP were returned to agricultural production, during the last 5 years resulting in a loss of soil C. However, positive increases in C stocks continue on the nearly 11 million hectares of land currently enrolled in the CRP, as well as from intensification of crop production by limiting the use of bare-summer fallow in semi-arid regions, increased hay production, and adoption of conservation tillage (i.e., reduced- and no-till practices).

The spatial variability in the 2013 annual CO_2 flux is displayed in Figure 6-8 and Figure 6-9 for C stock changes in mineral and organic soils, respectively. The highest rates of net C accumulation in mineral soils occurred in the Midwest, which is the region with the largest amounts of conservation tillage, with the next highest rates of accumulation in the South-central and Northwest regions of the United States. The regions with the highest rates of emissions from organic soils occur in the Southeastern Coastal Region (particularly Florida), upper Midwest and

[34] The Conservation Reserve Program (CRP) is a land conservation program administered by the Farm Service Agency (FSA). In exchange for a yearly rental payment, farmers enrolled in the program agree to remove environmentally sensitive land from agricultural production and plant species that will improve environmental health and quality. Contracts for land enrolled in CRP are 10-15 years in length. The long-term goal of the program is to re-establish valuable land cover to help improve water quality, prevent soil erosion, and reduce loss of wildlife habitat.

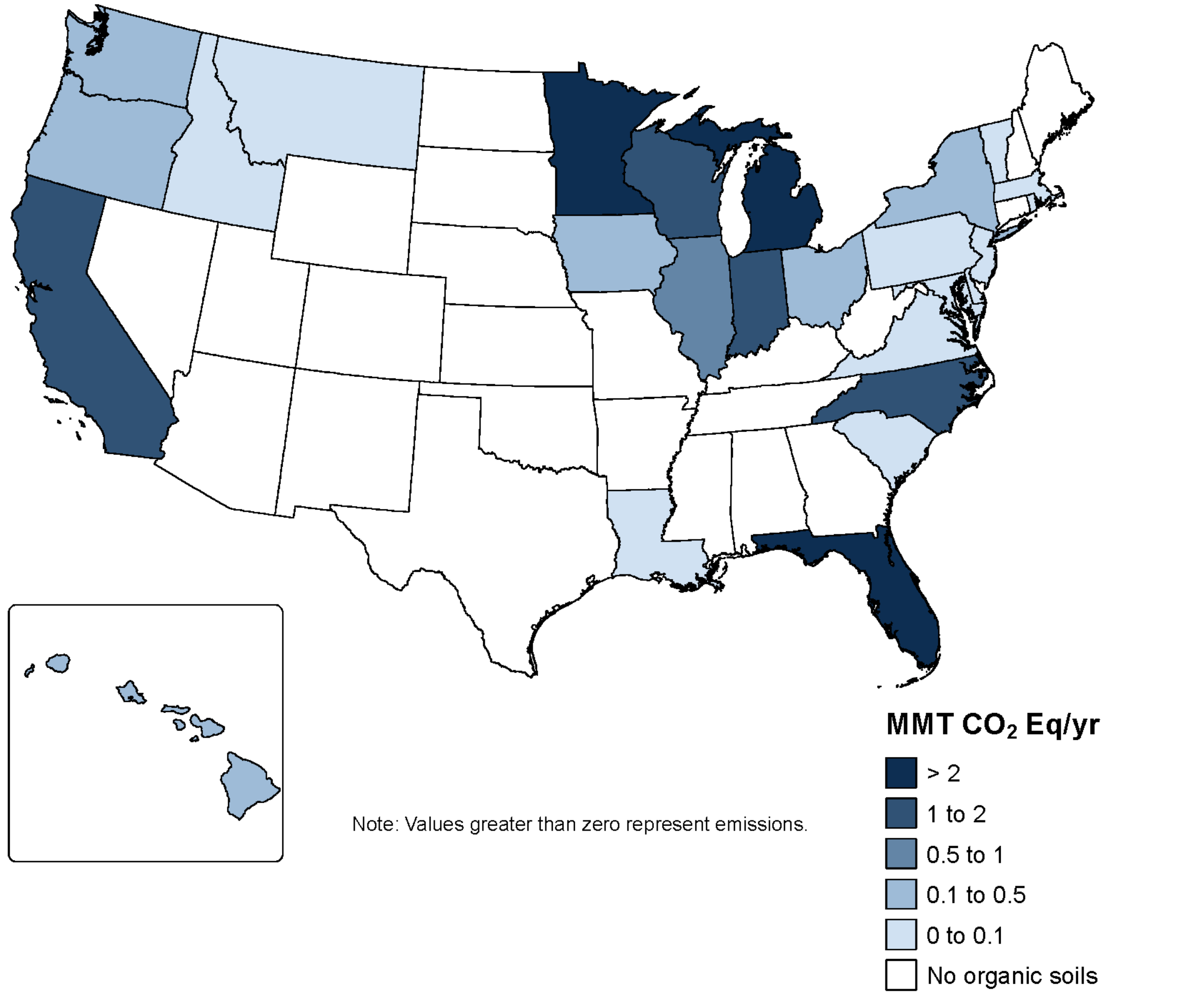
Northeast surrounding the Great Lakes, and the Pacific Coast (particularly California), which coincides with largest concentrations of organic soils in the United States that are used for agricultural production.

Figure 6-8: Total Net Annual CO_2 Flux for Mineral Soils under Agricultural Management within States, 2013, *Cropland Remaining Cropland*



Note: Values greater than zero represent emissions, and values less than zero represent sequestration. Map accounts for fluxes associated with the Tier 2 and 3 inventory computations. See methodology for additional details.

Figure 6-9: Total Net Annual CO_2 Flux for Organic Soils under Agricultural Management within States, 2013, *Cropland Remaining Cropland*



Methodology

The following section includes a description of the methodology used to estimate changes in soil C stocks for *Cropland Remaining Cropland*, including (1) agricultural land-use and management activities on mineral soils; and (2) agricultural land-use and management activities on organic soils.

Soil C stock changes were estimated for *Cropland Remaining Cropland* (as well as agricultural land falling into the IPCC categories *Land Converted to Cropland*, *Grassland Remaining Grassland*, and *Land Converted to Grassland*) according to land-use histories recorded in the USDA NRI survey (USDA-NRCS 2009). The NRI is a statistically-based sample of all non-federal land, and includes approximately 529,558 points in agricultural land for the conterminous United States and Hawaii.[35] Each point is associated with an "expansion factor" that allows scaling of C stock changes from NRI points to the entire country (i.e., each expansion factor represents the amount of area with the same land-use/management history as the sample point). Land-use and some management information (e.g., crop type, soil attributes, and irrigation) were originally collected for each NRI point on a 5-year cycle beginning in 1982. For cropland, data were collected for 4 out of 5 years in the cycle (i.e., 1979-1982, 1984-1987, 1989-1992,

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[35] NRI points were classified as agricultural if under grassland or cropland management between 1990 and 2007.

and 1994-1997). In 1998, the NRI program began collecting annual data, and data are currently available through 2010 (USDA-NRCS, 2013) although this Inventory only uses NRI data through 2007 because newer data were not made available in time to incorporate the additional years into this Inventory. NRI points were classified as *Cropland Remaining Cropland* in a given year between 1990 and 2007 if the land use had been cropland for 20 years.[36] Cropland includes all land used to produce food and fiber, or forage that is harvested and used as feed (e.g., hay and silage), in addition to cropland that has been enrolled in the CRP (i.e., considered reserve cropland).

Mineral Soil Carbon Stock Changes

An IPCC Tier 3 model-based approach (Ogle et al. 2010) was applied to estimate C stock changes for mineral soils on the majority of land that is used to produce annual crops in the United States. These crops include alfalfa hay, barley, corn, cotton, dry beans, grass hay, grass-clover hay, oats, onions, peanuts, potatoes, rice, sorghum, soybeans, sugar beets, sunflowers, tomatoes, and wheat. The model-based approach uses the DAYCENT biogeochemical model (Parton et al. 1998; Del Grosso et al. 2001, 2011) to estimate soil C stock changes and soil nitrous oxide emissions from agricultural soil management. Carbon and N dynamics are linked in plant-soil systems through the biogeochemical processes of microbial decomposition and plant production (McGill and Cole 1981). Coupling the two source categories (i.e., agricultural soil C and N_2O) in a single inventory analysis ensures that there is a consistent treatment of the processes and interactions between C and N cycling in soils.

The remaining crops on mineral soils were estimated using an IPCC Tier 2 method (Ogle et al. 2003), including some vegetables, tobacco, perennial/horticultural crops, and crops that are rotated with these crops. The Tier 2 method was also used for very gravelly, cobbly, or shaley soils (greater than 35 percent by volume). Mineral SOC stocks were estimated using a Tier 2 method for these areas because the DAYCENT model, which is used for the Tier 3 method, has not been fully tested for estimating C stock changes associated with these crops and rotations, as well as cobbly, gravelly, or shaley soils. An additional stock change calculation was estimated for mineral soils using Tier 2 emission factors to account for enrollment patterns in the CRP after 2007, which was not addressed by the Tier 3 method.

Further elaboration on the methodology and data used to estimate stock changes from mineral soils are described below and in Annex 3.12.

Tier 3 Approach

Mineral SOC stocks and stock changes were estimated using the DAYCENT biogeochemical[37] model (Parton et al. 1998; Del Grosso et al. 2001, 2011), which simulates cycling of C, N and other nutrients in cropland, grassland, forest, and savanna ecosystems. The DAYCENT model utilizes the soil C modeling framework developed in the Century model (Parton et al. 1987, 1988, 1994; Metherell et al. 1993), but has been refined to simulate dynamics at a daily time-step. Crop production is simulated with NASA-CASA production algorithm (Potter et al.1993, Potter et al. 2007) using the MODIS Enhanced Vegetation Index (EVI) products, MOD13Q1 and MYD13Q1, with a pixel resolution of 250 m. A prediction algorithm was developed to estimate EVI (Gurung et al. 2009) for gap-filling during years over the inventory time series when EVI data were not available (e.g., data from the MODIS sensor were only available after 2000 following the launch of the Aqua and Terra Satellites). The modeling approach uses daily weather data as an input, along with information about soil physical properties. Input data on land use and management are specified at a daily resolution and include land-use type, crop/forage type, and management activities (e.g., planting, harvesting, fertilization, manure amendments, tillage, irrigation, residue removal, grazing, and fire). The model simulates net primary productivity and C additions to soil, soil temperature, and water dynamics, in addition to turnover, stabilization, and mineralization of soil organic matter C and nutrients (N, P, K, S). This method is more accurate than the Tier 1 and 2 approaches provided by the IPCC (2006) because the simulation model treats changes as continuous over time as opposed to the simplified discrete changes represented in the default method (see Box 6-4 for additional information).

[36] NRI points were classified according to land-use history records starting in 1982 when the NRI survey began. Therefore, the classification prior to 2002 was based on less than 20 years of recorded land-use history for the time series.

[37] Biogeochemical cycles are the flow of chemical elements and compounds between living organisms and the physical environment

Box 6-4: Tier 3 Approach for Soil C Stocks Compared to Tier 1 or 2 Approaches

A Tier 3 model-based approach is used to estimate soil C stock changes on the majority of agricultural land on mineral soils. This approach results in a more complete accounting of soil C stock changes and entails several fundamental differences from the IPCC Tier 1 or 2 methods, as described below.

(1) The IPCC Tier 1 and 2 methods are simplified and classify land areas into discrete categories based on highly aggregated information about climate (six regions), soil (seven types), and management (eleven management systems) in the United States. In contrast, in the Tier 3 model, the same variables (i.e. climate, soils, and management systems) are represented in considerably more detail both temporally and spatially, and exhibit multi-dimensional interactions through the more complex model structure.

(2) The IPCC Tier 1 and 2 methods have a simplified spatial resolution, where, in the United States, data is aggregated to climate and soil regions. In contrast, the Tier 3 model uses more than 300,000 individual NRI point locations in individual fields.

(3) The IPCC Tier 1 and 2 methods use simplified equilibrium step changes for changes in carbon emissions. In contrast, the Tier 3 approach simulates a continuous time period. More specifically, the DAYCENT model (i.e., daily time-step version of the Century model) simulates soil C dynamics (and CO_2 emissions and uptake) on a daily time step based on C emissions and removals from plant production and decomposition processes. These changes in soil C stocks are influenced by multiple sources that affect primary production and decomposition, including changes in land use and management, weather variability and secondary feedbacks between management activities, climate, and soils.

Historical land-use patterns are simulated with DAYCENT based on the 2007 USDA NRI survey, in addition to information on irrigation (USDA-NRCS 2009). Additional sources of activity data were used to supplement the land-use information from NRI. The Conservation Technology Information Center (CTIC 2004) provided annual data on tillage activity at the county level since 1989, with adjustments for long-term adoption of no-till agriculture (Towery 2001). Information on fertilizer use and rates by crop type for different regions of the United States were obtained primarily from the USDA Economic Research Service Cropping Practices Survey (USDA-ERS 1997, 2011) with additional data from other sources, including the National Agricultural Statistics Service (NASS 1992, 1999, 2004). Frequency and rates of manure application to cropland during 1997 were estimated from data compiled by the USDA Natural Resources Conservation Service (Edmonds et al. 2003), and then adjusted using county-level estimates of manure available for application in other years. Specifically, county-scale ratios of manure available for application to soils in other years relative to 1997 were used to adjust the area amended with manure (see Annex 3.12 for further details). Greater availability of managed manure N relative to 1997 was, thus, assumed to increase the area amended with manure, while reduced availability of manure N relative to 1997 was assumed to reduce the amended area. Data on the county-level N available for application were estimated for managed systems based on the total amount of N excreted in manure minus N losses during storage and transport, and including the addition of N from bedding materials. Nitrogen losses include direct N_2O emissions, volatilization of ammonia and NO_x, runoff and leaching, and poultry manure used as a feed supplement. For unmanaged systems, it is assumed that no N losses or additions occur prior to the application of manure to the soil. More information on livestock manure production is available in the Manure Management, Section 5.2, and Annex 3.11.

Daily weather data were used as an input in the model simulations based on gridded data at a 32 km scale from the North America Regional Reanalysis Product (NARR) (Mesinger et al. 2006). Soil attributes were obtained from the Soil Survey Geographic Database (SSURGO) (Soil Survey Staff 2005). The C dynamics at each NRI point was simulated 100 times as part of the uncertainty analysis, yielding a total of over 18 million simulation runs for the analysis. Uncertainty in the C stock estimates from DAYCENT associated with parameterization and model algorithms were adjusted using a structural uncertainty estimator accounting for uncertainty in model algorithms and parameter values (Ogle et al. 2007, 2010). Carbon stocks and 95 percent confidence intervals were estimated for each year between 1990 and 2007, but C stock changes from 2008 to 2013 were assumed to be similar to 2007 for this Inventory due to a lack of activity data for these years. (Future Inventories will be updated with new activity data and the time series will be recalculated; see Planned Improvements section).

Tier 2 Approach

In the IPCC Tier 2 method, data on climate, soil types, land-use, and land management activity were used to classify land area and apply appropriate stock change factors (Ogle et al. 2003, 2006). Major Land Resource Areas (MLRAs) formed the base spatial unit for conducting the Tier 2 analysis. MLRAs represent a geographic unit with relatively similar soils, climate, water resources, and land uses (NRCS 1981). MLRAs were classified into climate regions according to the IPCC categories using the PRISM climate database of Daly et al. (1994), and the factors were assigned based on the land management systems in the MLRA in addition to the climate and soil types.

Reference C stocks were estimated using the National Soil Survey Characterization Database (NRCS 1997) with cultivated cropland as the reference condition, rather than native vegetation as used in IPCC (2006). Soil measurements under agricultural management are much more common and easily identified in the National Soil Survey Characterization Database (NRCS 1997) than are soils under a native condition, and therefore cultivated cropland provided a more robust sample for estimating the reference condition.

U.S.-specific stock change factors were derived from published literature to determine the impact of management practices on SOC storage (Ogle et al. 2003, Ogle et al. 2006). The factors include changes in tillage, cropping rotations, intensification, and land-use change between cultivated and uncultivated conditions. U.S. factors associated with organic matter amendments were not estimated due to an insufficient number of studies in the United States to analyze the impacts. Instead, factors from IPCC (2003) were used to estimate the effect of those activities.

Activity data were primarily based on the historical land-use/management patterns recorded in the 2007 NRI (USDA-NRCS 2009). Each NRI point was classified by land use, soil type, climate region (using PRISM data, Daly et al. 1994) and management condition. Classification of cropland area by tillage practice was based on data from the Conservation Technology Information Center (CTIC 2004, Towery 2001) as described above. Activity data on wetland restoration of Conservation Reserve Program land were obtained from Euliss and Gleason (2002). Manure N amendments over the inventory time period were based on application rates and areas amended with manure N from Edmonds et al. (2003), in addition to the managed manure production data discussed in the methodology subsection for the Tier 3 analysis.

Combining information from these data sources, SOC stocks for mineral soils were estimated 50,000 times for 1982, 1992, 1997, 2002 and 2007, using a Monte Carlo stochastic simulation approach and probability distribution functions for U.S.-specific stock change factors, reference C stocks, and land-use activity data (Ogle et al. 2002, Ogle et al. 2003, Ogle et al. 2006). The annual C flux for 1990 through 1992 was determined by calculating the average annual change in stocks between 1982 and 1992; annual C flux for 1993 through 1997 was determined by calculating the average annual change in stocks between 1992 and 1997; annual C flux for 1998 through 2002 was determined by calculating the average annual change in stocks between 1998 and 2002; and annual C flux from 2003 through 2013 was determined by calculating the average annual change in stocks between 2003 and 2007.

Additional Mineral C Stock Change

Annual C flux estimates for mineral soils between 2008 and 2013 were adjusted to account for additional C stock changes associated with gains or losses in soil C after 2007 due to changes in CRP enrollment (USDA-FSA 2013). The change in enrollment relative to 2007 was based on data from USDA-FSA (2013) for 2008 through 2013. The differences in mineral soil areas were multiplied by 0.5 metric tons C per hectare per year to estimate the net effect on soil C stocks. The stock change rate is based on country-specific factors and the IPCC default method (see Annex 3.12 for further discussion).

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Cropland Remaining Cropland* were estimated using the Tier 2 method provided in IPCC (2006), with U.S.-specific C loss rates (Ogle et al. 2003) rather than default IPCC rates. The final estimates included a measure of uncertainty as determined from the Monte Carlo Stochastic Simulation with 50,000 iterations. Emissions were based on the annual data from 1990 to 2007 for *Cropland Remaining Cropland* areas in the 2007 NRI (USDA-NRCS 2009). The annual emissions estimated for 2007 were applied to

2007 through 2013. (Future inventories will be updated with new activity data and the time series will be recalculated; see Planned Improvements section).

Uncertainty and Time-Series Consistency

Uncertainty associated with the *Cropland Remaining Cropland* land-use category was addressed for changes in agricultural soil C stocks (including both mineral and organic soils). Uncertainty estimates are presented in Table 6-21 for each subsource (mineral soil C stocks and organic soil C stocks) and the method that was used in the inventory analysis (i.e., Tier 2 and Tier 3). Uncertainty for the portions of the Inventory estimated with Tier 2 and 3 approaches was derived using a Monte Carlo approach (see Annex 3.12 for further discussion). Uncertainty estimates from each approach were combined using the error propagation equation in accordance with IPCC (2006). The combined uncertainty was calculated by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities. The combined uncertainty for soil C stocks in *Cropland Remaining Cropland* ranged from 152 percent below to 154 percent above the 2013 stock change estimate of -23.4 MMT CO_2 Eq.

Table 6-21: Approach 2 Quantitative Uncertainty Estimates for Soil C Stock Changes occurring within *Cropland Remaining Cropland* (MMT CO_2 Eq. and Percent)

Source	2013 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mineral Soil C Stocks: Cropland Remaining Cropland, Tier 3 Inventory Methodology	(49.3)	(83.7)	(14.9)	-70%	70%
Mineral Soil C Stocks: Cropland Remaining Cropland, Tier 2 Inventory Methodology	(2.8)	(5.1)	(0.9)	-80%	68%
Mineral Soil C Stocks: Cropland Remaining Cropland (Change in CRP enrollment relative to 2003)	6.6	3.3	9.9	-50%	50%
Organic Soil C Stocks: Cropland Remaining Cropland, Tier 2 Inventory Methodology	22.1	14.0	32.5	-37%	47%
Combined Uncertainty for Flux associated with Agricultural Soil Carbon Stock Change in Cropland Remaining Cropland	**(23.4)**	**(59.0)**	**12.7**	**-152%**	**154%**

[a] Range of flux estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
Note: Parentheses indicate net sequestration.

Uncertainty is also associated with lack of reporting of agricultural biomass and litter C stock changes. Biomass C stock changes are likely minor in perennial crops, such as orchards and nut plantations, given the small amount of change in land used to produce these commodities in the United States. In contrast, agroforestry practices, such as shelterbelts, riparian forests and intercropping with trees, may have led to significant changes in biomass C stocks, at least in some regions of the United States, but there are currently no datasets to evaluate the trends. Changes in litter C stocks are also assumed to be negligible in croplands over annual time frames, although there are certainly significant changes at sub-annual time scales across seasons. However, this trend may change in the future, particularly if crop residue becomes a viable feedstock for bioenergy production.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2013. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

Quality control measures included checking input data, model scripts, and results to ensure data were properly handled throughout the inventory process. Inventory reporting forms and text were reviewed and revised as needed to correct transcription errors. As discussed in the uncertainty section, results were compared to field measurements, and a statistical relationship was developed to assess uncertainties in the model's predictive capability. The comparisons included over 45 long-term experiments, representing about 800 combinations of management treatments across all of the sites (Ogle et al. 2007) (See Annex 3.12 for more information).

Recalculations Discussion

Methodological recalculations in the current Inventory were associated with the following improvements: 1) refining parameters associated with simulating crop production and carbon inputs to the soil in the DAYCENT biogeochemical model; 2) improving the model simulation of snow melt and water infiltration in soils; and 3) driving the DAYCENT simulations with updated input data for managed manure based on national livestock population. The change in SOC stocks increased by an average of 4.3 MMT CO_2 Eq. over the time series as a result of the improvements to the Inventory.

Planned Improvements

Two major planned improvements are underway. The first is to update the time series of land use and management data from the USDA NRI so that it is extended from 2008 through 2010 for both the Tier 2 and 3 methods (USDA-NRCS 2013). Fertilization and tillage activity data will also be updated as part of this improvement. The remote-sensing based data on the Enhanced Vegetation Index will be extended through 2010 in order to use the EVI data to drive crop production in DAYCENT. Overall, this improvement will extend the time series of activity data for the Tier 2 and 3 analyses through 2010.

The second major planned improvement is to analyze C stock changes on federal lands and Alaska for cropland and managed grassland, using the Tier 2 method for mineral and organic soils that is described earlier in this section. This analysis will initially focus on land use change, which typically has a larger impact on soil C stock changes, but will be further refined over time to incorporate more of the management data.

Other improvements are planned for the DAYCENT biogeochemical model. Specifically, senescence events following grain filling in crops, such as wheat, will also be further evaluated and refined as needed.

An improvement is also underway to simulate crop residue burning in the DAYCENT based on the amount of crop residues burned according to the data that is used in the Field Burning of Agricultural Residues source category (Section 5.5). This improvement will more accurately represent the C inputs to the soil that are associated with residue burning.

All of these improvements are expected to be completed for the 1990 through 2014 Inventory. However, the time line may be extended if there are insufficient resources to fund all or part of these planned improvements.

CO_2 Emissions from Agricultural Liming

IPCC (2006) recommends reporting CO_2 emissions from lime additions (in the form of crushed limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) to agricultural soils. Limestone and dolomite are added by land managers to increase soil pH (i.e., to reduce acidification). When these compounds come in contact with acid soils, they degrade, thereby generating CO_2. The rate and ultimate magnitude of degradation of applied limestone and dolomite depends on the soil conditions, soil type, climate regime, and the type of mineral applied. Emissions from liming of agricultural soils have fluctuated over the past 23 years, ranging from 3.7 MMT CO_2 Eq. to 5.9 MMT CO_2 Eq. In 2013, liming of agricultural soils in the United States resulted in emissions of 5.9 MMT CO_2 Eq. (1.6 MMT C), representing about a 27 percent increase in emissions since 1990 (see Table 6-22 and Table 6-23). The trend is driven entirely by the amount of lime and dolomite estimated to have been applied to soils over the time period.

Table 6-22: Emissions from Liming of Agricultural Soils (MMT CO_2 Eq.)

Source	1990		2005		2009	2010	2011	2012	2013
Limestone	4.1		3.9		3.4	4.3	3.4	4.3	4.4
Dolomite	0.6		0.4		0.3	0.5	0.4	1.5	1.5
Total[a]	**4.7**		**4.3**		**3.7**	**4.8**	**3.9**	**5.8**	**5.9**

[a] Also includes emissions from liming on *Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland*, and *Settlements Remaining Settlements* as it is not currently possible to apportion the data by land-use category.
Note: Totals may not sum due to independent rounding.

Table 6-23: Emissions from Liming of Agricultural Soils (MMT C)

Source	1990		2005		2009	2010	2011	2012	2013
Limestone	1.1		1.1		0.9	1.2	0.9	1.2	1.2
Dolomite	0.2		0.1		0.1	0.1	0.1	0.4	0.4
Total[a]	**1.3**		**1.2**		**1.0**	**1.3**	**1.1**	**1.6**	**1.6**

[a] Also includes emissions from liming on *Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland*, and *Settlements Remaining Settlements* as it is not currently possible to apportion the data by land-use category.
Note: Totals may not sum due to independent rounding.

Methodology

CO_2 emissions from degradation of limestone and dolomite applied to agricultural soils were estimated using a Tier 2 methodology consistent with IPCC (2006). The annual amounts of limestone and dolomite applied (see Table 6-24) were multiplied by CO_2 emission factors from West and McBride (2005). These emission factors (0.059 metric ton C/metric ton limestone, 0.064 metric ton C/metric ton dolomite) are lower than the IPCC default emission factors because they account for the portion of agricultural lime that may leach through the soil and travel by rivers to the ocean (West and McBride 2005). This analysis of lime dissolution is based on liming occurring in the Mississippi River basin, where the vast majority of all U.S. liming takes place (West 2008). U.S. liming that does not occur in the Mississippi River basin tends to occur under similar soil and rainfall regimes, and, thus, the emission factor is appropriate for use across the United States (West 2008). The annual application rates of limestone and dolomite were derived from estimates and industry statistics provided in the *Minerals Yearbook* and *Mineral Industry Surveys* (Tepordei 1993 through 2006; Willett 2007a, 2007b, 2009, 2010, 2011a, 2011b, 2013a and 2014; USGS 2008 through 2014). To develop these data, the U.S. Geological Survey (USGS; U.S. Bureau of Mines prior to 1997) obtained production and use information by surveying crushed stone manufacturers. Because some manufacturers were reluctant to provide information, the estimates of total crushed limestone and dolomite production and use were divided into three components: (1) production by end-use, as reported by manufacturers (i.e., "specified" production); (2) production reported by manufacturers without end-uses specified (i.e., "unspecified" production); and (3) estimated additional production by manufacturers who did not respond to the survey (i.e., "estimated" production).

Box 6-5: Comparison of the Tier 2 U.S. Inventory Approach and IPCC (2006) Default Approach

Emissions from liming of agricultural soils were estimated using a Tier 2 methodology based on liming emission factors specific to the United States that are lower than the IPCC (2006) emission default factors, and are specific to U.S. soil conditions under which liming occurs. For example, as described previously, most liming in the United States occurs in the Mississippi River basin, or in areas that have similar soil and rainfall regimes as the Mississippi River basin. Under such soil conditions, a significant portion of dissolved agricultural lime is predicted to leach through the soil and travels by rivers to the ocean, the majority of which is then predicted to precipitate in the ocean as $CaCO_3$ (West and McBride 2005). Therefore, the U.S. specific emissions factors (0.059 metric ton C/metric ton limestone and 0.064 metric ton C/metric ton dolomite) are about half of the IPCC (2006) emission factors (0.12 metric ton C/metric ton limestone and 0.13 metric ton C/metric ton dolomite). For comparison, the 2013 U.S. emissions from liming of agricultural soils are 5.9 MMT CO_2 Eq. using the U.S.-specific, West and McBride (2005) emission factors and 12.0 MMT CO_2 Eq. using the IPCC (2006) emission factors.

The "unspecified" and "estimated" amounts of crushed limestone and dolomite applied to agricultural soils were calculated by multiplying the percentage of total "specified" limestone and dolomite production applied to agricultural soils by the total amounts of "unspecified" and "estimated" limestone and dolomite production. In other words, the proportion of total "unspecified" and "estimated" crushed limestone and dolomite that was applied to agricultural soils (as opposed to other uses of the stone) was assumed to be proportionate to the amount of "specified" crushed limestone and dolomite that was applied to agricultural soils. In addition, data were not available for 1990, 1992, and 2013 on the fractions of total crushed stone production that were limestone and dolomite, and on the fractions of limestone and dolomite production that were applied to soils. To estimate the 1990 and 1992 data, a set of average fractions were calculated using the 1991 and 1993 data. These average fractions were applied to the quantity of "total crushed stone produced or used" reported for 1990 and 1992 in the 1994 *Minerals Yearbook* (Tepordei 1996). To estimate 2013 data, 2012 fractions were applied to a 2013 estimate of total crushed stone presented in the USGS *Mineral Industry Surveys: Crushed Stone and Sand and Gravel in the First Quarter of 2014* (USGS 2014).

The primary source for limestone and dolomite activity data is the *Minerals Yearbook*, published by the Bureau of Mines through 1994 and by the USGS from 1995 to the present. In 1994, the "Crushed Stone" chapter in the *Minerals Yearbook* began rounding (to the nearest thousand metric tons) quantities for total crushed stone produced or used. It then reported revised (rounded) quantities for each of the years from 1990 to 1993. In order to minimize the inconsistencies in the activity data, these revised production numbers have been used in all of the subsequent calculations. Since limestone and dolomite activity data are also available at the state level, the national-level estimates reported here were broken out by state, although state-level estimates are not reported here. Also, it is important to note that all emissions from liming are accounted for under *Cropland Remaining Cropland* because it is not currently possible to apportion the data to each agricultural land-use category (i.e., *Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland*, and *Settlements Remaining Settlements*). The majority of liming in the United States occurs on *Cropland Remaining Cropland.*

Table 6-24: Applied Minerals (MMT)

Mineral	1990		2005		2009	2010	2011	2012	2013
Limestone[a]	19.0		18.1		15.7	20.0	15.9	19.9	20.4
Dolomite[a]	2.4		1.9		1.2	1.9	1.9	6.3	6.4

[a] Data represent amounts applied to *Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland*, and *Settlements Remaining Settlements* as it is not currently possible to apportion the data by land-use category.

Uncertainty and Time-Series Consistency

Uncertainty regarding limestone and dolomite activity data inputs was estimated at ±15 percent and assumed to be uniformly distributed around the inventory estimate (Tepordei 2003, Willett 2013b). Analysis of the uncertainty associated with the emission factors included the following: the fraction of agricultural lime dissolved by nitric acid versus the fraction that reacts with carbonic acid, and the portion of bicarbonate that leaches through the soil and is transported to the ocean. Uncertainty regarding the time associated with leaching and transport was not accounted for, but should not change the uncertainty associated with CO_2 emissions (West 2005). The uncertainties associated with the fraction of agricultural lime dissolved by nitric acid and the portion of bicarbonate that leaches through the soil were each modeled as a smoothed triangular distribution between ranges of zero percent to 100 percent. The uncertainty surrounding these two components largely drives the overall uncertainty estimates reported below. More information on the uncertainty estimates for Liming of Agricultural Soils is contained within the Uncertainty Annex.

A Monte Carlo (Approach 2) uncertainty analysis was applied to estimate the uncertainty of CO_2 emissions from liming of agricultural soils. The results of the Approach 2 quantitative uncertainty analysis are summarized in Table 6-25. CO_2 emissions from Liming of Agricultural Soils in 2013 were estimated to be between 0.7 and 12.1 MMT CO_2 Eq. at the 95 percent confidence level. This indicates a range of 88 percent below to 103 percent above the 2013 emission estimate of 5.9 MMT CO_2 Eq.

Table 6-25: Approach 2 Quantitative Uncertainty Estimates for CO_2 Emissions from Liming of Agricultural Soils (MMT CO_2 Eq. and Percent)

Source	Gas	2013 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Liming of Agricultural Soils[b]	CO_2	5.9	0.7	12.1	-88%	103%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
[b] Also includes emissions from liming on *Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland*, and *Settlements Remaining Settlements* as it is not currently possible to apportion the data by land-use category.

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2013. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

A source-specific QA/QC plan for Liming was developed and implemented. This effort included a Tier 1 analysis, as well as portions of a Tier 2 analysis. The Tier 2 procedures focused on comparing the magnitude of emission factors historically to attempt to identify any outliers or inconsistencies. No problems were found.

Recalculations Discussion

Several adjustments were made in the current Inventory to improve the results. In the previous Inventory, to estimate 2012 data, 2011 fractions were applied to a 2012 estimate of total crushed stone presented in the USGS *Mineral Industry Surveys: Crushed Stone and Sand and Gravel in the First Quarter of 2013* (USGS 2013). Since publication of the previous Inventory, the *Minerals Yearbook* has published actual quantities of crushed stone sold or used by producers in the United States in 2012. These values have replaced those used in the previous Inventory to calculate the quantity of minerals applied to soil and the emissions from liming of agricultural soils. Compared to the estimates used in the previous Inventory for 2012, the updated activity data for 2012 are approximately 3.8 MMT greater for limestone, and approximately 4.4 MMT greater for dolomite. As a result, the reported emissions from liming of agricultural soils for 2012 increased by about 47 percent.

CO_2 Emissions from Urea Fertilization

The use of urea ($CO(NH_2)_2$) as a fertilizer leads to CO_2 emissions through the release of CO_2 that was fixed during the industrial production process. In the presence of water and urease enzymes, urea is converted into ammonium (NH_4^+), hydroxyl ion (OH), and bicarbonate (HCO_3^-). The bicarbonate then evolves into CO_2 and water. Emissions from urea fertilization in the United States totaled 4.0 MMT CO_2 Eq. (1.1 MMT C) in 2013 (Table 6-26 and Table 6-27). Due to an increase in the use of urea as a fertilizer, emissions from urea have increased 66 percent between 1990 and 2013.

Table 6-26: CO_2 Emissions from Urea Fertilization (MMT CO_2 Eq.)

Source	1990	2005	2009	2010	2011	2012	2013
Urea Fertilization[a]	2.4	3.5	3.6	3.8	4.1	4.2	4.0

[a] Also includes emissions from urea fertilization on *Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Settlements Remaining Settlements*, and *Forest Land Remaining Forest Land* because it is not currently possible to apportion the data by land-use category.

Table 6-27: CO_2 Emissions from Urea Fertilization (MMT C)

Source	1990	2005	2009	2010	2011	2012	2013
Urea Fertilization[a]	0.7	1.0	1.0	1.0	1.1	1.2	1.1

[a] Also includes emissions from urea fertilization on *Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Settlements Remaining Settlements*, and *Forest Land Remaining Forest Land* because it is not currently possible to apportion the data by land-use category.

Methodology

CO_2 emissions from the application of urea to agricultural soils were estimated using the IPCC (2006) Tier 1 methodology. The annual amounts of urea applied to croplands (see Table 6-28) were derived from the state-level fertilizer sales data provided in *Commercial Fertilizers* (TVA 1991, 1992, 1993, 1994; AAPFCO 1995 through 2014). These amounts were multiplied by the default IPCC (2006) emission factor (0.20 metric tons of C per metric ton of urea), which is equal to the C content of urea on an atomic weight basis. Because fertilizer sales data are reported in fertilizer years (July previous year through June current year), a calculation was performed to convert the data to calendar years (January through December). According to monthly fertilizer use data (TVA 1992b), 35 percent of total fertilizer used in any fertilizer year is applied between July and December of the previous calendar year, and 65 percent is applied between January and June of the current calendar year. For example, for the 2000 fertilizer year, 35 percent of the fertilizer was applied in July through December 1999, and 65 percent was applied in January through June 2000. Fertilizer sales data for the 2013 fertilizer year (i.e., July 2012 through June 2013) were not available in time for publication. Accordingly, urea application in the 2013 fertilizer year was estimated using a linear, least squares trend of consumption over the previous five years (2008 through 2012). A trend of five years was chosen as opposed to a longer trend as it best captures the current inter-state and inter-annual variability in consumption. First, January through June 2013 urea consumption was estimated using the approach described above, after which the percentage change in use from the previous year (i.e., January through June 2012) was determined. Next, the July through December 2012 data was multiplied by the same percent change to estimate the July through December 2013 urea consumption (assuming a constant percentage change between 2012 and 2013). State-level estimates of CO_2 emissions from the application of urea to agricultural soils were summed to estimate total emissions for the entire United States. Since urea activity data are also available at the state level, the national-level estimates reported here were broken out by state, although state-level estimates are not reported here. Also, it is important to note that all emissions from urea fertilization are accounted for under *Cropland Remaining Cropland* because it is not currently possible to apportion the data to each agricultural land-use category (i.e., *Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland*, and *Settlements Remaining Settlements*). The majority of urea fertilization in the United States occurs on *Cropland Remaining Cropland.*

Table 6-28: Applied Urea (MMT)

	1990		2005		2009	2010	2011	2012	2013
Urea Fertilizer[a]	3.3		4.8		4.8	5.2	5.6	5.8	5.5

[a] These numbers represent amounts applied to all agricultural land, including *Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Settlements Remaining Settlements*, and *Forest Land Remaining Forest Land* because it is not currently possible to apportion the data by land-use category.

Uncertainty and Time-Series Consistency

Uncertainty estimates are presented in Table 6-29 for Urea Fertilization. An Approach 2 Monte Carlo analysis was completed. The largest source of uncertainty was the default emission factor, which assumes that 100 percent of the C in $CO(NH_2)_2$ applied to soils is ultimately emitted into the environment as CO_2. This factor does not incorporate the possibility that some of the C may be retained in the soil. The emission estimate is, therefore, likely to be an overestimate. In addition, each urea consumption data point has an associated uncertainty. Urea for non-fertilizer use, such as aircraft deicing, may be included in consumption totals; it was determined through personal communication with Fertilizer Regulatory Program Coordinator David L. Terry (2007), however, that this amount is most likely very small. Research into aircraft deicing practices also confirmed that urea is used minimally in the industry; a 1992 survey found a known annual usage of approximately 2,000 tons of urea for deicing; this would constitute 0.06 percent of the 1992 consumption of urea (EPA 2000). Similarly, surveys conducted from 2002 to 2005 indicate that total urea use for deicing at U.S. airports is estimated to be 3,740 metric tons per year, or less than 0.07 percent of the fertilizer total for 2007 (Itle 2009). Lastly, there is uncertainty surrounding the assumptions behind the calculation that converts fertilizer years to calendar years. CO_2 emissions from urea fertilization of agricultural soils in 2013 were estimated to be between 2.3 and 4.1 MMT CO_2 Eq. at the 95 percent confidence level. This indicates a range of 42 percent below to 3 percent above the 2013 emission estimate of 4.0 MMT CO_2 Eq.

Table 6-29: Quantitative Uncertainty Estimates for CO_2 Emissions from Urea Fertilization (MMT CO_2 Eq. and Percent)

Source	Gas	2013 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Urea Fertilization	CO_2	4.0	2.3	4.1	-42%	3%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2013. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

A source-specific QA/QC plan for Urea was developed and implemented. This effort included a Tier 1 analysis, as well as portions of a Tier 2 analysis. The Tier 2 procedures focused on comparing the magnitude of emission factors historically to attempt to identify any outliers or inconsistencies. No problems were found.

Recalculations Discussion

In the current Inventory, the 2011 and 2012 emissions estimates were updated to reflect the urea application reported in the *Commercial Fertilizers Report* for the 2012 fertilizer year (July through December 2011, January through June, 2012). Specifically, the 2011 emissions estimates were revised to reflect the July to December 2011 urea application data. This recalculation resulted in actual emissions that are 3 percent higher than the previously estimated 2011 emissions. For 2012, the January through June, 2012 actual urea application rates were used to replace the estimates from the previous year, and the July through December rates of application were estimated using the methodology described above (i.e., the July through December, 2011 urea rates were multiplied by the percentage change in rates from January through June, 2011 to January through June, 2012). The updated activity data for 2012 are approximately 1,068 kt greater than the amount estimated for 2012 in the previous Inventory. As a result, the reported emissions from urea for 2012 in the current Inventory are 23 percent higher than the estimated emission reported for 2012 in the previous Inventory.

Planned Improvements

The primary planned improvement is to investigate using a Tier 2 or Tier 3 approach, which would utilize country-specific information to estimate a more precise emission factor. This possibility was investigated for the current Inventory, but no options were identified for updating to a Tier 2 or Tier 3 approach.

6.5 Land Converted to Cropland (IPCC Source Category 4B2)

Land Converted to Cropland includes all cropland in an Inventory year that had been in another land use(s) during the previous 20 years[38] (USDA-NRCS 2009). For example, grassland or forestland converted to cropland during the past 20 years would be reported in this category. Recently-converted lands are retained in this category for 20 years as recommended in the IPCC guidelines (IPCC 2006). This Inventory includes all privately-owned croplands in the conterminous United States and Hawaii, but does not include the approximately 100,000 hectares of *Land Converted to Cropland* on federal lands and a minor amount of *Land Converted to Cropland* in Alaska. Consequently there is a discrepancy between the total amount of managed area in *Land Converted to Cropland* (see Section 6.1) and the cropland area included in the Inventory. Improvements are underway to include federal croplands in future C inventories.

Background on agricultural carbon (C) stock changes is provided in section 6.4 *Cropland Remaining Cropland* and therefore will only be briefly summarized here. Soils are the largest pool of C in agricultural land, and also have the greatest potential for long-term storage or release of C, because biomass and dead organic matter C pools are relatively small and ephemeral compared with soils, with the exception of C stored in perennial woody crop biomass. The IPCC (2006) guidelines recommend reporting changes in soil organic carbon (SOC) stocks due to (1) agricultural land-use and management activities on mineral soils, and (2) agricultural land-use and management activities on organic soils.[39]

Land use and management of mineral soils in *Land Converted to Cropland* was the largest contributor to C loss throughout the time series, accounting for approximately 70 percent of the emissions in the category (Table 6-30 and Table 6-31). The conversion of grassland to cropland was the largest source of soil C loss (accounting for approximately 65 percent of the emissions in the category), though losses declined over the time series. The net flux of C from soil stock changes in 2013 was 16.1 MMT CO_2 Eq. (4.4 MMT C) in 2013, including 11.3 MMT CO_2 Eq. (3.1 MMT C) from mineral soils and 4.8 MMT CO_2 Eq. (1.3 MMT C) from drainage and cultivation of organic soils.

Table 6-30: Net CO_2 Flux from Soil C Stock Changes in *Land Converted to Cropland* by Land Use Change Category (MMT CO_2 Eq.)

Soil Type	1990	2005	2009	2010	2011	2012	2013
Grassland Converted to Cropland							
Mineral	20.0	14.0	10.6	10.6	10.6	10.5	10.6
Organic	2.5	4.3	4.0	4.0	4.0	4.0	4.0
Forest Converted to Cropland							
Mineral	1.5	0.3	0.3	0.3	0.3	0.3	0.3
Organic	(0.2)	0.3	0.2	0.2	0.2	0.2	0.2
Other Lands Converted Cropland							
Mineral	0.3	0.1	0.1	0.1	0.1	0.1	0.1
Organic	+	+	+	+	+	+	+
Settlements Converted Cropland							
Mineral	0.6	0.3	0.3	0.3	0.3	0.3	0.3
Organic	+	0.2	0.2	0.2	0.2	0.2	0.2
Wetlands Converted Cropland							
Mineral	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Organic	(0.2)	0.3	0.4	0.4	0.4	0.4	0.4
Total Mineral Soil Flux	**22.4**	**14.8**	**11.4**	**11.4**	**11.4**	**11.3**	**11.3**

[38] The 2009 USDA National Resources Inventory (NRI) land-use survey points were classified according to land-use history records starting in 1982 when the NRI survey began. Consequently the classifications from 1990 to 2001 were based on less than 20 years.

[39] CO_2 emissions associated with liming urea fertilization are also estimated but included in 7.4 *Cropland Remaining Cropland*.

Total Organic Soil Flux	**2.1**	**5.1**	**4.8**	**4.8**	**4.8**	**4.8**	**4.8**
Total Net Flux	**24.5**	**19.8**	**16.2**	**16.2**	**16.2**	**16.1**	**16.1**

Note: Estimates after 2007 are based on NRI data from 2007 and therefore may not fully reflect changes occurring in the latter part of the time series.
+ Does not exceed 0.05 MMT CO_2 Eq.

Table 6-31: Net CO_2 Flux from Soil C Stock Changes in *Land Converted to Cropland* (MMT C)

Soil Type	1990	2005	2009	2010	2011	2012	2013
Grassland Converted to Cropland							
Mineral	5.4	3.8	2.9	2.9	2.9	2.9	2.9
Organic	0.7	1.2	1.1	1.1	1.1	1.1	1.1
Forest Converted to Cropland							
Mineral	0.4	0.1	0.1	0.1	0.1	0.1	0.1
Organic	(0.1)	0.1	0.1	0.1	0.1	0.1	0.1
Other Lands Converted Cropland							
Mineral	0.1	+	+	+	+	+	+
Organic	+	+	+	+	+	+	+
Settlements Converted Cropland							
Mineral	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Organic	+	0.1	+	+	+	+	+
Wetlands Converted Cropland							
Mineral	0.1	+	+	+	+	+	+
Organic	(0.1)	0.1	0.1	0.1	0.1	0.1	0.1
Total Mineral Soil Flux	**6.1**	**4.0**	**3.1**	**3.1**	**3.1**	**3.1**	**3.1**
Total Organic Soil Flux	**0.6**	**1.4**	**1.3**	**1.3**	**1.3**	**1.3**	**1.3**
Total Net Flux	**6.7**	**5.4**	**4.4**	**4.4**	**4.4**	**4.4**	**4.4**

Note: Estimates after 2007 are based on NRI data from 2007 and therefore may not fully reflect changes occurring in the latter part of the time series.
+ Does not exceed 0.05 MMT C
Parentheses indicate net sequestration.

The spatial variability in the 2013 annual flux in CO_2 from mineral soils is displayed in Figure 6-10 and from organic soils in Figure 6-11. Losses occurred in most regions of the United States. In particular, conversion of grassland and forestland to cropland led to enhanced decomposition of soil organic matter and a net loss of C from the soil pool. The regions with the highest rates of emissions from organic soils coincide with the largest concentrations of organic soils used for agricultural production, including Southeastern Coastal Region (particularly Florida), upper Midwest and Northeast surrounding the Great Lakes, and the Pacific Coast (particularly California).

Figure 6-10: Total Net Annual CO_2 Flux for Mineral Soils under Agricultural Management within States, 2013, *Land Converted to Cropland*

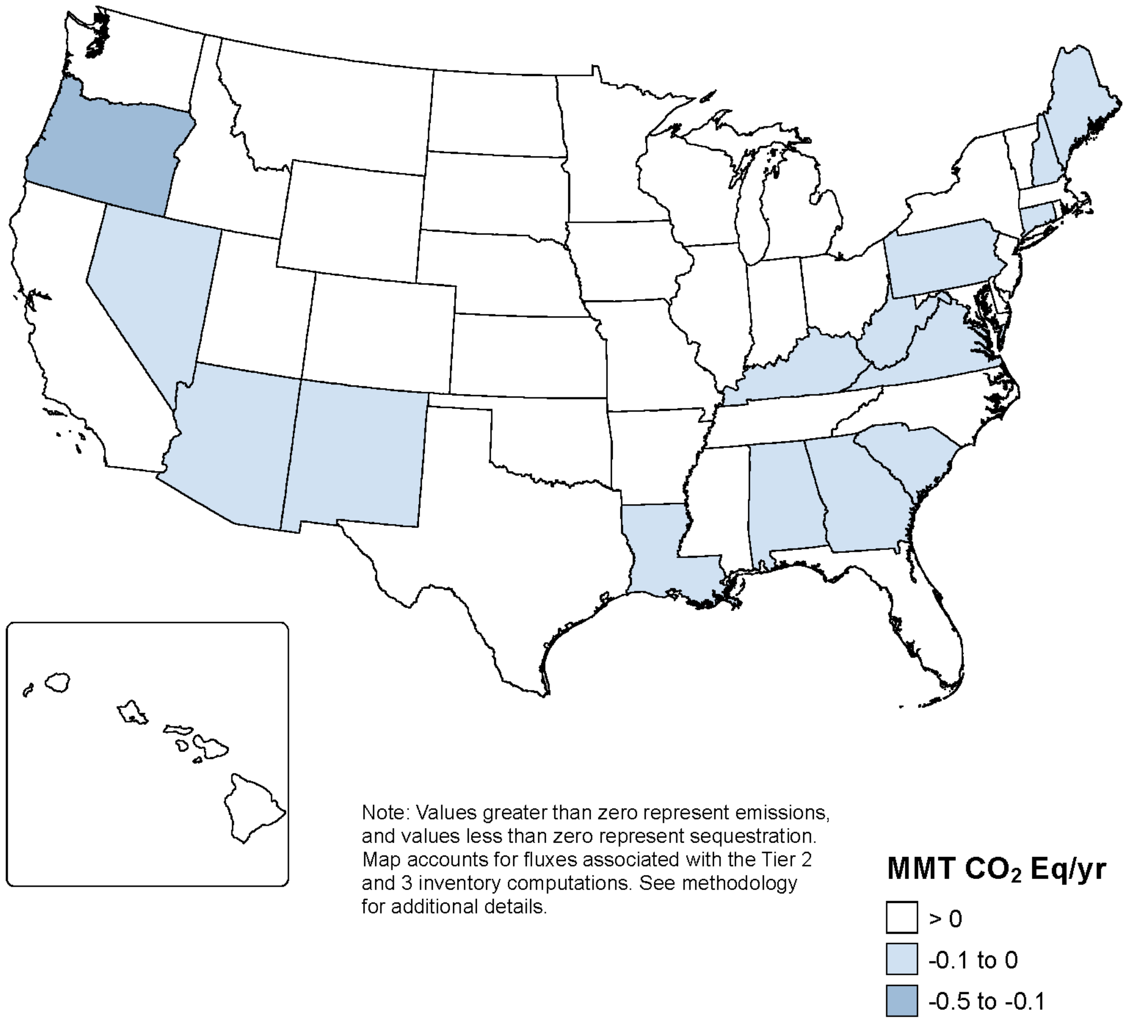
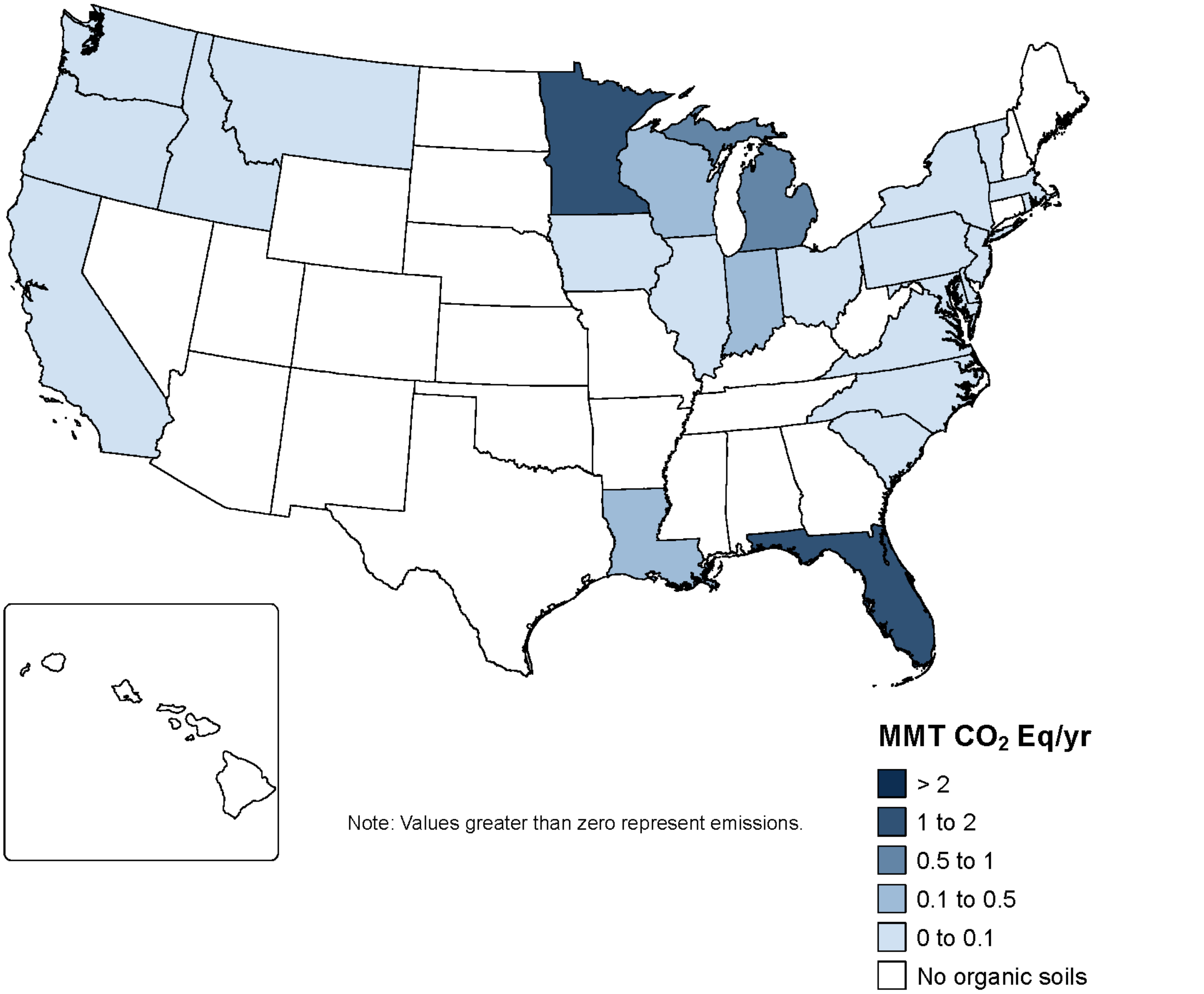


Figure 6-11: Total Net Annual CO_2 Flux for Organic Soils under Agricultural Management within States, 2013, *Land Converted to Cropland*



Methodology

The following section includes a description of the methodology used to estimate changes in soil C stocks for *Land Converted to Cropland*, including (1) agricultural land-use and management activities on mineral soils; and (2) agricultural land-use and management activities on organic soils Biomass and litter C stock changes associated with conversion of forest to cropland are not explicitly included in this category, but are included in the *Forest Land Remaining Forest Land* section. Further elaboration on the methodologies and data used to estimate stock changes for mineral and organic soils are provided in the *Cropland Remaining Cropland* section and Annex 3.12.

Soil C stock changes were estimated for *Land Converted to Cropland* according to land-use histories recorded in the 2007 USDA NRI survey (USDA-NRCS 2009). Land-use and some management information (e.g., crop type, soil attributes, and irrigation) were originally collected for each NRI point on a 5-year cycle beginning in 1982. In 1998, the NRI program began collecting annual data, and data are currently available through 2010 (USDA-NRCS 2013). However, this Inventory only uses NRI data through 2007 because newer data were not made available in time to incorporate the additional years into this Inventory. NRI points were classified as *Land Converted to Cropland* in a given year between 1990 and 2007 if the land use was cropland but had been another use during the previous 20 years. Cropland includes all land used to produce food or fiber, or forage that is harvested and used as feed (e.g., hay and silage).

Mineral Soil Carbon Stock Changes

An IPCC Tier 3 model-based approach (Ogle et al. 2010) was applied to estimate C stock changes for mineral soils on the majority of land that is used to produce annual crops in the United States. These crops include alfalfa hay, barley, corn, cotton, dry beans, grass hay, grass-clover hay, oats, onions, peanuts, potatoes, rice, sorghum, soybeans, sugar beets, sunflowers, tomatoes, and wheat. Soil C stock changes on the remaining soils were estimated with the IPCC Tier 2 method (Ogle et al. 2003), including land used to produce some vegetables, tobacco, perennial/horticultural crops and crops rotated with these crops; land on very gravelly, cobbly, or shaley soils (greater than 35 percent by volume); and land converted from forest or federal ownership.[40]

Tier 3 Approach

For the Tier 3 method, mineral SOC stocks and stock changes were estimated using the DAYCENT biogeochemical[41] model (Parton et al. 1998; Del Grosso et al. 2001, 2011). The DAYCENT model utilizes the soil C modeling framework developed in the Century model (Parton et al. 1987, 1988, 1994; Metherell et al. 1993), but has been refined to simulate dynamics at a daily time-step. National estimates were obtained by using the model to simulate historical land-use change patterns as recorded in the USDA NRI (USDA-NRCS 2009). C stocks and 95 percent confidence intervals were estimated for each year between 1990 and 2007, but C stock changes from 2008 to 2013 were assumed to be similar to 2007 due to a lack of activity data for these years. (Future inventories will be updated with new activity data and the time series will be recalculated; See Planned Improvements section in *Cropland Remaining Cropland*). The methods used for *Land Converted to Cropland* are the same as those described in the Tier 3 portion of *Cropland Remaining Cropland* section for mineral soils.

Tier 2 Approach

For the mineral soils not included in the Tier 3 analysis, SOC stock changes were estimated using a Tier 2 Approach for *Land Converted to Cropland* as described in the Tier 2 portion of the *Cropland Remaining Cropland* section for mineral soils.

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Land Converted to Cropland* were estimated using the Tier 2 method provided in IPCC (2006), with U.S.-specific C loss rates (Ogle et al. 2003) as described in the *Cropland Remaining Cropland* section for organic soils.

Uncertainty and Time-Series Consistency

Uncertainty analysis for mineral soil C stock changes using the Tier 3 and Tier 2 methodologies were based on the same method described for *Cropland Remaining Cropland*. The uncertainty for annual C emission estimates from drained organic soils in *Land Converted to Cropland* was estimated using Tier 2, as described in the *Cropland Remaining Cropland* section.

Uncertainty estimates are presented in Table 6-32 for each subsource (i.e., mineral soil C stocks and organic soil C stocks) and method that was used in the Inventory analysis (i.e., Tier 2 and Tier 3). Uncertainty for the portions of the Inventory estimated with Tier 2 and 3 approaches was derived using a Monte Carlo approach (see Annex 3.12 for further discussion). Uncertainty estimates from each approach were combined using the error propagation equation in accordance with IPCC (2006), i.e., by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities. The combined uncertainty for soil C stocks in *Land Converted to Cropland* ranged from 72 percent below to 81 percent above the 2013 stock change estimate of 16.1 MMT CO_2 Eq.

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[40] Federal land is not a land use, but rather an ownership designation that is treated as forest or nominal grassland for purposes of these calculations. The specific use for federal lands is not identified in the NRI survey (USDA-NRCS 2009).

[41] Biogeochemical cycles are the flow of chemical elements and compounds between living organisms and the physical environment.

Table 6-32: Approach 2 Quantitative Uncertainty Estimates for Soil C Stock Changes occurring within *Land Converted to Cropland* (MMT CO_2 Eq. and Percent)

Source	2013 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Grassland Converted to Cropland	**14.6**	**3.0**	**27.7**	**-80%**	**90%**
Mineral Soil C Stocks: Tier 3	9.8	(1.3)	20.9	-114%	114%
Mineral Soil C Stocks: Tier 2	0.8	0.4	1.2	-49%	54%
Organic Soil C Stocks: Tier 2	4.0	0.7	10.9	-83%	172%
Forests Converted to Cropland	**0.5**	**0.2**	**1.1**	**-53%**	**123%**
Mineral Soil C Stocks: Tier 2	0.3	0.1	0.4	-49%	54%
Organic Soil C Stocks: Tier 2	0.2	0.0	0.8	-100%	258%
Other Lands Converted to Cropland	**0.1**	**0.1**	**0.2**	**-49%**	**54%**
Mineral Soil C Stocks: Tier 2	0.1	0.1	0.2	-49%	54%
Organic Soil C Stocks: Tier 2	NA	NA	NA	NA	NA
Settlements Converted to Cropland	**0.5**	**0.3**	**0.7**	**-36%**	**41%**
Mineral Soil C Stocks: Tier 2	0.3	0.2	0.5	-49%	54%
Organic Soil C Stocks: Tier 2	0.2	0.1	0.3	-46%	63%
Wetlands Converted to Croplands	**0.4**	**0.2**	**0.7**	**-45%**	**57%**
Mineral Soil C Stocks: Tier 2	0.1	0.04	0.1	-49%	54%
Organic Soil C Stocks: Tier 2	0.4	0.2	0.6	-53%	68%
Total: Land Converted to Cropland	**16.1**	**4.5**	**29.2**	**-72%**	**81%**
Mineral Soil C Stocks: Tier 3	**9.8**	**(1.3)**	**20.9**	**-114%**	**114%**
Mineral Soil C Stocks: Tier 2	**1.6**	**1.1**	**2.0**	**-28%**	**31%**
Organic Soil C Stocks: Tier 2	**4.8**	**1.4**	**11.7**	**-70%**	**145%**

Note: Parentheses indicate negative values or net sequestration.
NA: Other land by definition does not include organic soil (see Section 6.1—Representation of the U.S. Land Base). Consequently, no land areas, C stock changes, or uncertainty results are estimated for land use conversions from Other lands to Croplands and Other lands to Grasslands on organic soils.
[a] Range of flux estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Uncertainty is also associated with lack of reporting of agricultural biomass and litter C stock changes other than the loss of forest biomass and litter, which is reported in the *Forest Land Remaining Forest Land* section of this report. Biomass C stock changes are likely minor in perennial crops, such as orchards and nut plantations, given the small amount of change in land used to produce these commodities in the United States. In contrast, agroforestry practices, such as shelterbelts, riparian forests and intercropping with trees, may have led to significant changes in biomass C stocks, at least in some regions of the United States, but there are currently no datasets to evaluate the trends. Changes in litter C stocks are also assumed to be negligible in croplands over annual time frames, although there are certainly significant changes at sub-annual time scales across seasons. However, this trend may change in the future, particularly if crop residue becomes a viable feedstock for bioenergy production.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2013. Details on the emission trends through time are described in more detail in the Methodology section, above.

Recalculations Discussion

Methodological recalculations in the current Inventory were associated with the following improvements: 1) refining parameters associated with simulating crop production and carbon inputs to the soil in the DAYCENT biogeochemical model; 2) improving the model simulation of snow melt and water infiltration in soils; and 3) driving the DAYCENT simulations with updated input data for the excretion of C and N onto Pasture/Range/Paddock and N additions from managed manure based on national livestock population. Change in SOC stocks declined by an average of 0.9 MMT CO_2 Eq. over the time series as a result of these improvements to the Inventory.

QA/QC and Verification

See QA/QC and Verification section under *Cropland Remaining Cropland*.

Planned Improvements

Soil C stock changes with land use conversion from forest land to cropland are undergoing further evaluation to ensure consistency in the time series. Different methods are used to estimate soil C stock changes in forest land and croplands, and while the areas have been reconciled between these land uses, there has been limited evaluation of the consistency in C stock changes with conversion from forest land to cropland. This planned improvement may not be fully implemented for two more years, depending on resource availability. Additional planned improvements are discussed in the *Cropland Remaining Cropland* section.

6.6 Grassland Remaining Grassland (IPCC Source Category 4C1)

Grassland Remaining Grassland includes all grassland in an Inventory year that had been classified as grassland for the previous 20 years[42] (USDA-NRCS 2009). Grassland includes pasture and rangeland that are primarily used for livestock grazing. Rangelands are typically extensive areas of native grassland that are not intensively managed, while pastures are typically seeded grassland (possibly following tree removal) that may also have additional management, such as irrigation or interseeding of legumes. This Inventory includes all privately-owned grasslands in the conterminous United States and Hawaii, but does not include the 75 million hectares of *Grassland Remaining Grassland* on federal lands or the 36 million hectares of *Grassland Remaining Grassland* in Alaska. This leads to a discrepancy with the total amount of managed area in *Grassland Remaining Grassland* (see Section 6.1 — Representation of the U.S. Land Base) and the grassland area included in the *Grassland Remaining Grassland* (IPCC Source Category 4C1—Section 6.6).

Background on agricultural carbon (C) stock changes is provided in the section 6.4, *Cropland Remaining Cropland*, and will only be summarized here. Soils are the largest pool of C in agricultural land, and also have the greatest potential for longer-term storage or release of C, because biomass and dead organic matter C pools are relatively small and ephemeral compared to the soil C pool, with the exception of C stored in tree and shrub biomass that occurs in grasslands. The IPCC (2006) guidelines recommend reporting changes in soil organic C (SOC) stocks due to (1) agricultural land-use and management activities on mineral soils, and (2) agricultural land-use and management activities on organic soils.[43]

In *Grassland Remaining Grassland*, there has been considerable variation in soil C flux between 1990 and 2013. These changes are driven by variability in weather patterns and associated interaction with land management activity. Even in the years with larger total changes in stocks, changes remain small on a per hectare rate. Land use and management increased soil C in mineral soils of *Grassland Remaining Grassland* between 1990 and 2006, after which the trend was reversed to small declines in soil C. In contrast, organic soils have lost relatively small amounts of C annually from 1990 through 2013. While the overall trend was a gain in soil C in *Grassland Remaining Grassland* from 1990 to 2003, the last decade has seen small losses in soil C during most years (Table 6-33 and Table 6-34). Overall, from 1990 to 2013, the net change in soil C flux increased by 14.0 MMT CO_2 Eq. (3.8 MMT C). Current estimates for flux from soil C stock changes in 2013 are estimated at a total of 12.1 MMT CO_2 Eq. (3.3

[42] The 2009 USDA National Resources Inventory (NRI) land-use survey points were classified according to land-use history records starting in 1982 when the NRI survey began. Consequently the classifications from 1990 to 2001 were based on less than 20 years

[43] CO_2 emissions associated with liming and urea fertilization are also estimated but included in 6.4 Cropland Remaining Cropland.

MMT C), with 9.1 MMT CO_2 Eq. (2.5 MMT C) from mineral soils and 3.0 MMT CO_2 Eq. (0.8 MMT C) from organic soils.

Table 6-33: Net CO_2 Flux from Soil C Stock Changes in *Grassland Remaining Grassland* (MMT CO_2 Eq.)

Soil Type	1990	2005	2009	2010	2011	2012	2013
Mineral Soils	(6.5)	1.2	8.7	8.7	8.7	8.5	9.1
Organic Soils	4.6	3.1	3.0	3.0	3.0	3.0	3.0
Total Net Flux	**(1.9)**	**4.2**	**11.7**	**11.7**	**11.7**	**11.5**	**12.1**

Note: Totals may not sum due to independent rounding. Estimates after 2007 are based on NRI data from 2007 and therefore may not fully reflect changes occurring in the latter part of the time series. Parentheses indicate net sequestration.

Table 6-34: Net CO_2 Flux from Soil C Stock Changes in *Grassland Remaining Grassland* (MMT C)

Soil Type	1990	2005	2009	2010	2011	2012	2013
Mineral Soils	(1.8)	0.3	2.4	2.4	2.4	2.3	2.5
Organic Soils	1.3	0.8	0.8	0.8	0.8	0.8	0.8
Total Net Flux	**(0.5)**	**1.2**	**3.2**	**3.2**	**3.2**	**3.1**	**3.3**

Note: Totals may not sum due to independent rounding. Estimates after 2007 are based on NRI data from 2007 and therefore may not fully reflect changes occurring in the latter part of the time series. Parentheses indicate net sequestration.

The spatial variability in the 2013 annual flux in CO_2 from mineral is displayed in Figure 6-12 and organic soils in Figure 6-13. Although relatively small on a per-hectare basis, grassland gained soil C in several regions during 2013, including the Northeast, Southeast, portions of the Midwest, and Pacific Coastal Region. The regions with the highest rates of emissions from organic soils coincide with the largest concentrations of organic soils used for managed grassland, including the Southeastern Coastal Region (particularly Florida), upper Midwest and Northeast surrounding the Great Lakes, and the Pacific Coast (particularly California).

Figure 6-12: Total Net Annual CO_2 Flux for Mineral Soils under Agricultural Management within States, 2013, *Grassland Remaining Grassland*

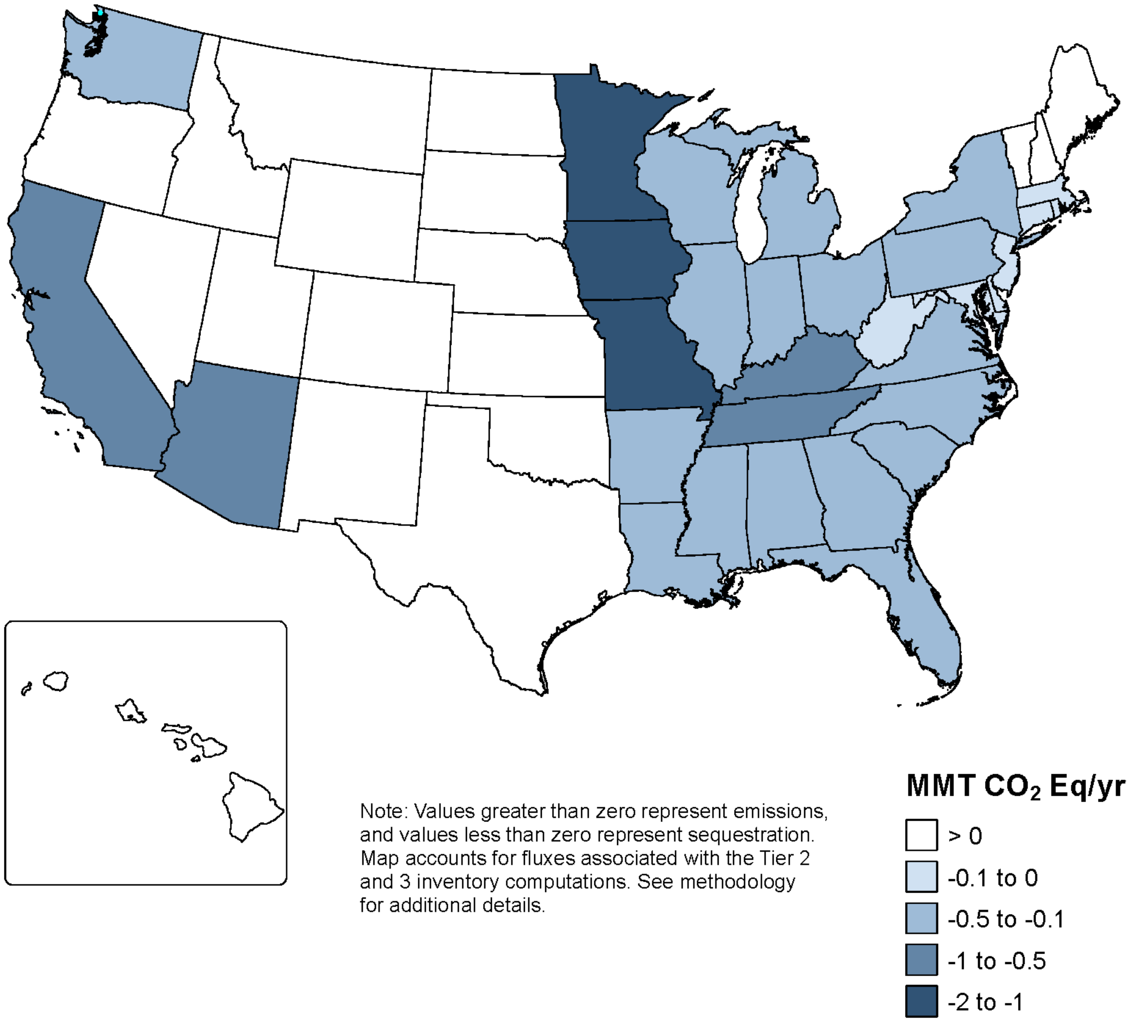
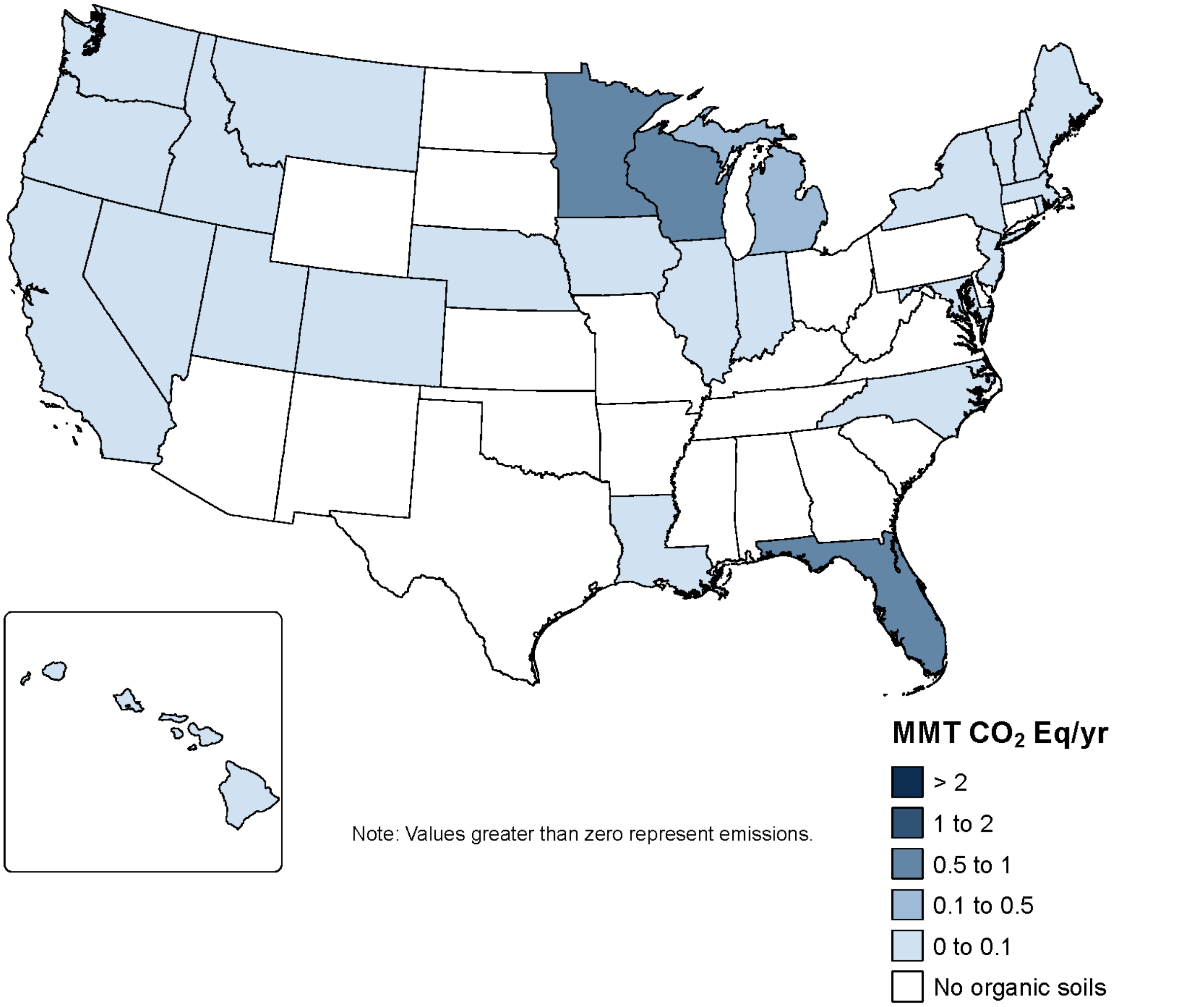


Figure 6-13: Total Net Annual CO_2 Flux for Organic Soils under Agricultural Management within States, 2013, *Grassland Remaining Grassland*



Methodology

The following section includes a brief description of the methodology used to estimate changes in soil C stocks for *Grassland Remaining Grassland*, including (1) agricultural land-use and management activities on mineral soils; and (2) agricultural land-use and management activities on organic soils. Further elaboration on the methodologies and data used to estimate stock changes from mineral and organic soils are provided in the *Cropland Remaining Cropland* section and Annex 3.12.

Soil C stock changes were estimated for *Grassland Remaining Grassland* according to land use histories recorded in the 2007 USDA NRI survey (USDA-NRCS 2009). Land-use and some management information (e.g., crop type, soil attributes, and irrigation) were originally collected for each NRI point on a 5-year cycle beginning in 1982. In 1998, the NRI program initiated annual data collection, and the annual data are currently available through 2010 (USDA-NRCS 2013). However, this Inventory only uses NRI data through 2007 because newer data were not made available in time to incorporate the additional years into this Inventory. NRI points were classified as *Grassland Remaining Grassland* in a given year between 1990 and 2007 if the land use had been grassland for 20 years.

Mineral Soil Carbon Stock Changes

An IPCC Tier 3 model-based approach (Ogle et al. 2010) was applied to estimate C stock changes for most mineral soils in *Grassland Remaining Grassland*. The C stock changes for the remaining soils were estimated with an IPCC Tier 2 method (Ogle et al. 2003), including gravelly, cobbly, or shaley soils (greater than 35 percent by volume) and additional stock changes associated with sewage sludge amendments.

Tier 3 Approach

Mineral SOC stocks and stock changes for *Grassland Remaining Grassland* were estimated using the DAYCENT biogeochemical[44] model (Parton et al. 1998; Del Grosso et al. 2001, 2011), as described in *Cropland Remaining Cropland*. The DAYCENT model utilizes the soil C modeling framework developed in the Century model (Parton et al. 1987, 1988, 1994; Metherell et al. 1993), but has been refined to simulate dynamics at a daily time-step. Historical land-use and management patterns were used in the DAYCENT simulations as recorded in the USDA NRI survey, with supplemental information on fertilizer use and rates from the USDA Economic Research Service Cropping Practices Survey (USDA-ERS 1997, 2011) and National Agricultural Statistics Service (NASS 1992, 1999, 2004). Frequency and rates of manure application to grassland during 1997 were estimated from data compiled by the USDA Natural Resources Conservation Service (Edmonds, et al. 2003), and then adjusted using county-level estimates of manure available for application in other years. Specifically, county-scale ratios of manure available for application to soils in other years relative to 1997 were used to adjust the area amended with manure (see *Cropland Remaining Cropland* for further details). Greater availability of managed manure nitrogen (N) relative to 1997 was, thus, assumed to increase the area amended with manure, while reduced availability of manure N relative to 1997 was assumed to reduce the amended area.

The amount of manure produced by each livestock type was calculated for managed and unmanaged waste management systems based on methods described in *Manure Management*, Section 5.2, and Annex 3.11. Manure N deposition from grazing animals (i.e., PRP manure) was an input to the DAYCENT model (see Annex 3.11), and included approximately 91 percent of total PRP manure (the remainder is deposited on federal lands, which are not included in this Inventory). C stocks and 95 percent confidence intervals were estimated for each year between 1990 and 2007, but C stock changes from 2008 to 2013 were assumed to be similar to 2007 due to a lack of activity data for these years. (Future inventories will be updated with new activity data and the time series will be recalculated; See Planned Improvements section in *Cropland Remaining Cropland*). The methods used for *Grassland remaining Grassland* are the same as those described in the Tier 3 portion of *Cropland Remaining Cropland* section for mineral soils.

Tier 2 Approach

The Tier 2 approach is based on the same methods described in the Tier 2 portion of *Cropland Remaining Cropland* section for mineral soils.

Additional Mineral C Stock Change Calculations

A Tier 2 method was used to adjust annual C flux estimates for mineral soils between 1990 and 2013 to account for additional C stock changes associated with sewage sludge amendments. Estimates of the amounts of sewage sludge N applied to agricultural land were derived from national data on sewage sludge generation, disposition, and N content. Total sewage sludge generation data for 1988, 1996, and 1998, in dry mass units, were obtained from EPA (1999) and estimates for 2004 were obtained from an independent national biosolids survey (NEBRA 2007). These values were linearly interpolated to estimate values for the intervening years, and linearly extrapolated to estimate values for years since 2004. N application rates from Kellogg et al. (2000) were used to determine the amount of area receiving sludge amendments. Although sewage sludge can be added to land managed for other land uses, it was assumed that agricultural amendments occur in grassland. Cropland is not likely to be amended with sewage sludge due to the high metal content and other pollutants in human waste. The soil C storage rate was estimated at

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[44] Biogeochemical cycles are the flow of chemical elements and compounds between living organisms and the physical environment.

0.38 metric tons C per hectare per year for sewage sludge amendments to grassland. The stock change rate is based on country-specific factors and the IPCC default method (see Annex 3.12 for further discussion).

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Grassland Remaining Grassland* were estimated using the Tier 2 method provided in IPCC (2006), which utilizes U.S.-specific C loss rates (Ogle et al. 2003) rather than default IPCC rates. For more information, see the *Cropland Remaining Cropland* section for organic soils.

Uncertainty and Time-Series Consistency

Uncertainty estimates are presented in Table 6-35 for each subsource (i.e., mineral soil C stocks and organic soil C stocks) disaggregated to the level of the inventory methodology employed (i.e., Tier 2 and Tier 3). Uncertainty for the portions of the Inventory estimated with Tier 2 and 3 approaches was derived using a Monte Carlo approach (see Annex 3.12 for further discussion). Uncertainty estimates from each approach were combined using the error propagation equation in accordance with IPCC (2006), i.e., by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities. The combined uncertainty for soil C stocks in *Grassland Remaining Grassland* ranged from 297 percent below to 297 percent above the 2013 stock change estimate of 12.1 MMT CO_2 Eq. The large relative uncertainty is due to the small net flux estimate in 2013.

Table 6-35: Approach 2 Quantitative Uncertainty Estimates for C Stock Changes Occurring Within *Grassland Remaining Grassland* (MMT CO_2 Eq. and Percent)

Source	2013 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mineral Soil C Stocks Grassland Remaining Grassland, Tier 3 Methodology	10.3	(25.5)	46.2	-347%	347%
Mineral Soil C Stocks: Grassland Remaining Grassland, Tier 2 Methodology	0.1	0.0	0.2	-86%	109%
Mineral Soil C Stocks: Grassland Remaining Grassland, Tier 2 Methodology (Change in Soil C due to Sewage Sludge Amendments)	(1.4)	(2.1)	(0.7)	-50%	50%
Organic Soil C Stocks: Grassland Remaining Grassland, Tier 2 Methodology	3.0	1.6	4.9	-46%	63%
Combined Uncertainty for Flux Associated with Agricultural Soil Carbon Stock Change in Grassland Remaining Grassland	**12.1**	**(23.8)**	**48.0**	**-297%**	**297%**

Note: Parentheses indicate negative values.
[a] Range of flux estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Uncertainty is also associated with a lack of reporting on agricultural biomass and litter C stock changes and non-CO_2 greenhouse gas emissions from burning. Biomass C stock changes may be significant for managed grasslands with woody encroachment that has not attained enough tree cover to be considered forest lands. Grassland burning is not as common in the United States as in other regions of the world, but fires do occur through both natural ignition sources and prescribed burning. Changes in litter C stocks are assumed to be negligible in grasslands over annual time frames, although there are certainly significant changes at sub-annual time scales across seasons.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2013. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

Quality control measures included checking input data, model scripts, and results to ensure data were properly handled through the inventory process. In the previous Inventory, DAYCENT was used to simulate the PRP manure N input with automated routines, but errors occurred leading to a mismatch between the amount of manure N excreted according to the *Manure Management* data, relative to the amount simulated in DAYCENT. This error appears to be corrected based on internal checks, and should provide internal consistency between the *Manure Management* data and the *Agricultural Soil Management* and LULUCF inventories.

Inventory reporting forms and text were reviewed and revised as needed to correct transcription errors. Modeled results were compared to measurements from several long-term grazing experiments (see Annex 3.12 for more information).

Recalculations Discussion

Methodological recalculations in the current Inventory were associated with the following improvements, including 1) improving the model simulation of snow melt and water infiltration in soils; and 2) driving the DAYCENT simulations with updated input data for the excretion of C and N onto Pasture/Range/Paddock and N additions from managed manure based on national livestock population. As a result of these improvements to the Inventory, changes in SOC stocks declined by an average of 1.76 MMT CO_2 eq. annually over the time series.

Planned Improvements

One of the key planned improvements for *Grassland Remaining Grassland* is to develop an inventory of carbon stock changes for the 75 million hectares of federal grasslands in the western United States. While federal grasslands likely have minimal changes in land management and C stocks, improvements are underway to include these grasslands in future C Inventories. Grasslands in Alaska will also be further evaluated in the future. This is a significant improvement and estimates are expected to be available for the 1990-2014 Inventory. Another key planned improvement is to estimate non-CO_2 greenhouse gas emissions from burning of grasslands. For information about other improvements, see the Planned Improvements section in *Cropland Remaining Cropland*.

6.7 Land Converted to Grassland (IPCC Source Category 4C2)

Land Converted to Grassland includes all grassland in an Inventory year that had been in another land use(s) during the previous 20 years[45] (USDA-NRCS 2009). For example, cropland or forestland converted to grassland during the past 20 years would be reported in this category. Recently-converted lands are retained in this category for 20 years as recommended by IPCC (2006). Grassland includes pasture and rangeland that are used primarily for livestock grazing. Rangelands are typically extensive areas of native grassland that are not intensively managed, while pastures are typically seeded grassland (possibly following tree removal) that may also have additional management, such as irrigation or interseeding of legumes. This Inventory includes all privately-owned grasslands in the conterminous United States and Hawaii, but does not but does not include the 800,000 to 850,000 hectares of *Land Converted to Grassland* on federal lands or *Land Converted to Grassland* in Alaska. Consequently there is a discrepancy between the total amount of managed area for *Land Converted to Grassland* (see Section 6.1—Representation of the U.S. Land Base) and the grassland area included in *Land Converted to Grassland* (IPCC Source Category 4C2—Section 6.7).

[45] The 2009 USDA National Resources Inventory (NRI) land-use survey points were classified according to land-use history records starting in 1982 when the NRI survey began. Consequently the classifications from 1990 to 2001 were based on less than 20 years.

Background on agricultural carbon (C) stock changes is provided in *Cropland Remaining Cropland* and therefore will only be briefly summarized here. Soils are the largest pool of C in agricultural land, and also have the greatest potential for long-term storage or release of C, because biomass and dead organic matter C pools are relatively small and ephemeral compared with soils, with the exception of C stored in tree and shrub biomass that occurs in grasslands. IPCC (2006) recommend reporting changes in soil organic C (SOC) stocks due to (1) agricultural land-use and management activities on mineral soils, and (2) agricultural land-use and management activities on organic soils.[46]

Land use and management of mineral soils in *Land Converted to Grassland* led to an increase in soil C stocks between 1990 and 2013 (see Table 6-36 and Table 6-37). The net C flux from soil C stock changes for mineral soils between 1990 and 2013 led to a decrease of 1.7 MMT CO_2 Eq. (0.5 MMT C) in the atmosphere. In contrast, over the same period, drainage of organic soils for grassland management led to an increase in C emissions to the atmosphere of 0.3 MMT CO_2 Eq. (0.1 MMT C). The flux associated with soil C stock changes in 2013 is estimated at a net uptake of 8.8 MMT CO_2 Eq. (-2.4 MMT C) from the atmosphere.

Table 6-36: Net CO_2 Flux from Soil C Stock Changes for *Land Converted to Grassland* (MMT CO_2 Eq.)

Soil Type	1990		2005		2009	2010	2011	2012	2013
Cropland Converted to Grassland									
Mineral	(6.4)		(9.0)		(8.8)	(8.8)	(8.7)	(8.6)	(8.6)
Organic	0.5		1.0		0.9	0.9	0.9	0.9	0.9
Forest Converted to Grassland									
Mineral	(1.1)		(0.4)		(0.4)	(0.4)	(0.4)	(0.4)	(0.4)
Organic	0.1		0.1		0.1	0.1	0.1	0.1	0.1
Other Lands Converted Grassland									
Mineral	(0.2)		(0.2)		(0.2)	(0.2)	(0.2)	(0.2)	(0.2)
Organic	+		+		+	+	+	+	+
Settlements Converted Grassland									
Mineral	(0.4)		(0.5)		(0.5)	(0.5)	(0.5)	(0.5)	(0.5)
Organic	+		+		+	+	+	+	+
Wetlands Converted Grassland									
Mineral	(0.1)		(0.1)		(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
Organic	0.1		0.1		0.1	0.1	0.1	0.1	0.1
Total Mineral Soil Flux	**(8.2)**		**(10.3)**		**(10.0)**	**(10.0)**	**(10.0)**	**(9.9)**	**(9.9)**
Total Organic Soil Flux	**0.8**		**1.3**		**1.1**	**1.1**	**1.1**	**1.1**	**1.1**
Total Net Flux	**(7.4)**		**(9.0)**		**(8.9)**	**(8.9)**	**(8.9)**	**(8.8)**	**(8.8)**

Note: Estimates after 2007 are based on NRI data from 2007 and therefore may not fully reflect changes occurring in the latter part of the time series. Parentheses indicate net sequestration.
+ Does not exceed 0.05 MMT CO_2 Eq.

Table 6-37: Net CO_2 Flux from Soil C Stock Changes for *Land Converted to Grassland* (MMT C)

Soil Type	1990		2005		2009	2010	2011	2012	2013
Cropland Converted to Grassland									
Mineral	(1.7)		(2.5)		(2.4)	(2.4)	(2.4)	(2.4)	(2.3)
Organic	0.1		0.3		0.2	0.2	0.2	0.2	0.2
Forest Converted to Grassland									
Mineral	(0.3)		(0.1)		(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
Organic	+		+		+	+	+	+	+
Other Lands Converted Grassland									
Mineral	(0.1)		(0.0)		(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
Organic	+		+		+	+	+	+	+
Settlements Converted Grassland									
Mineral	(0.1)		(0.1)		(0.1)	(0.1)	(0.1)	(0.1)	(0.1)

[46] CO_2 emissions associated with liming are also estimated but included in 6.4 Cropland Remaining Cropland.

Organic	+	+	+	+	+	+	+
Wetlands Converted Grassland							
Mineral	+	+	+	+	+	+	+
Organic	+	+	+	+	+	+	+
Total Mineral Soil Flux	**(2.2)**	**(2.8)**	**(2.7)**	**(2.7)**	**(2.7)**	**(2.7)**	**(2.7)**
Total Organic Soil Flux	**0.2**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**
Total Net Flux	**(2.0)**	**(2.5)**	**(2.4)**	**(2.4)**	**(2.4)**	**(2.4)**	**(2.4)**

Note: Estimates after 2007 are based on NRI data from 2007 and therefore may not fully reflect changes occurring in the latter part of the time series.
Parentheses indicate net sequestration.
+ Does not exceed 0.05 MMT CO_2 Eq.

The spatial variability in the 2013 annual flux in CO_2 from mineral soils is displayed in Figure 6-14 and from organic soils in Figure 6-15. The soil C stock increased in most states for *Land Converted to Grassland*, which was driven by conversion of annual cropland into continuous pasture. The largest gains were in the Southeastern region, Northeast, South-Central, Midwest, and northern Great Plains. The regions with the highest rates of emissions from organic soils coincide with the largest concentrations of organic soils used for managed grasslands, including Southeastern Coastal Region (particularly Florida), upper Midwest and Northeast surrounding the Great Lakes, and the Pacific Coast (particularly California).

Figure 6-14: Total Net Annual CO_2 Flux for Mineral Soils under Agricultural Management within States, 2013, *Land Converted to Grassland*

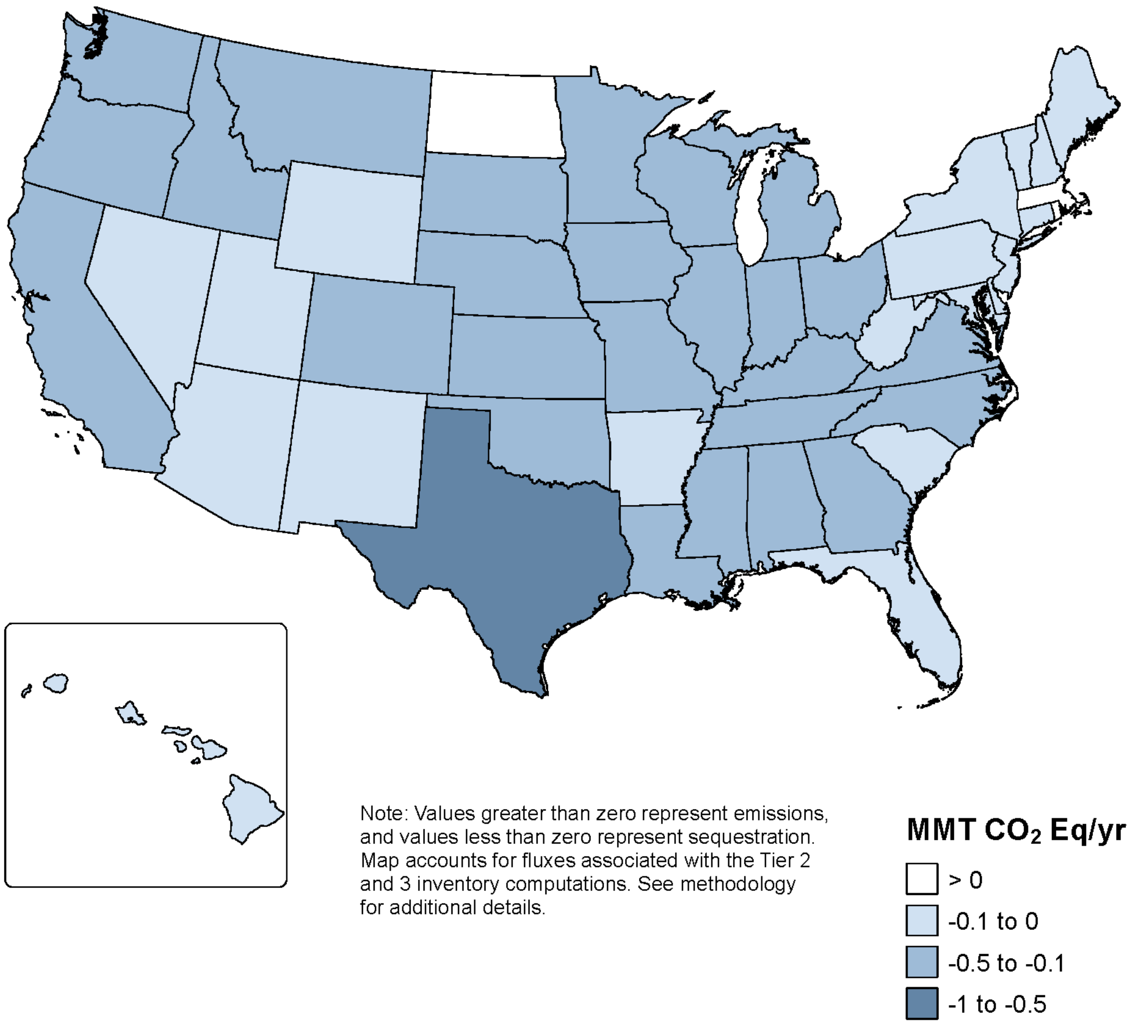
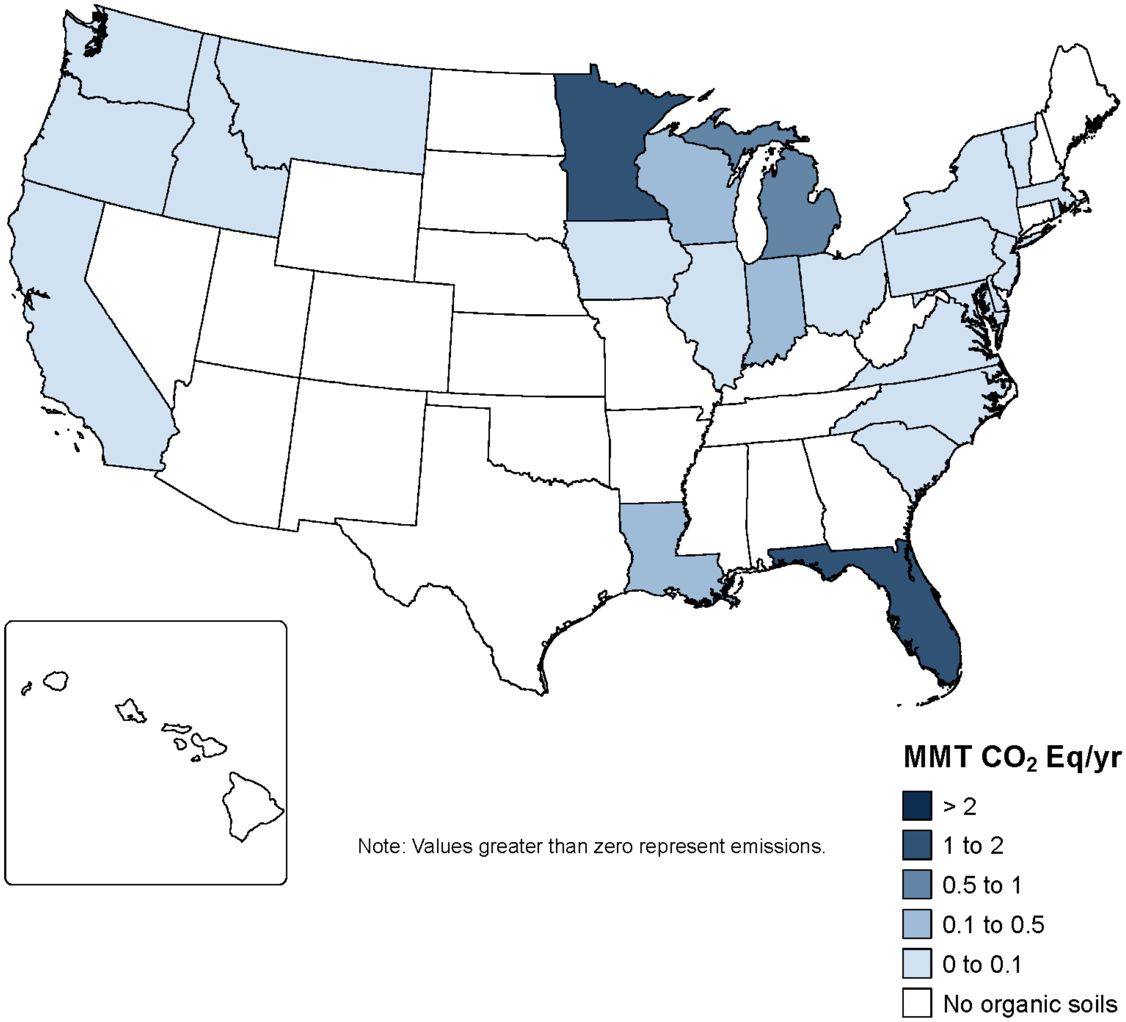


Figure 6-15: Total Net Annual CO_2 Flux for Organic Soils under Agricultural Management within States, 2013, *Land Converted to Grassland*



Methodology

The following section includes a description of the methodology used to estimate changes in soil C stocks for *Land Converted to Grassland*, including (1) agricultural land-use and management activities on mineral soils; and (2) agricultural land-use and management activities on organic soils. Biomass and litter C stock changes associated with conversion of forest to grassland are not explicitly included in this category, but are included in the *Forest Land Remaining Forest Land* section. Further elaboration on the methodologies and data used to estimate stock changes for mineral and organic soils are provided in the *Cropland Remaining Cropland* section and Annex 3.12.

Soil C stock changes were estimated for *Land Converted to Grassland* according to land-use histories recorded in the 2009 USDA NRI survey (USDA-NRCS 2009). Land use and some management information (e.g., crop type, soil attributes, and irrigation) were originally collected for each NRI point on a 5-year cycle beginning in 1982. In 1998, the NRI program initiated annual data collection, and the annual and data are currently available through 2010 (USDA-NRCS 2013). However, this Inventory only uses NRI data through 2007 because newer data were not made available in time to incorporate the additional years into this Inventory. NRI points were classified as *Land Converted to Grassland* in a given year between 1990 and 2007 if the land use was grassland but had been classified as another use during the previous 20 years.

Mineral Soil Carbon Stock Changes

An IPCC Tier 3 model-based approach (Ogle et al. 2010) was applied to estimate C stock changes for *Land Converted to Grassland* on most mineral soils. C stock changes on the remaining soils were estimated with an IPCC Tier 2 approach (Ogle et al. 2003), including prior cropland used to produce vegetables, tobacco, and perennial/horticultural crops; land areas with very gravelly, cobbly, or shaley soils (greater than 35 percent by volume); and land converted from forest.[47]

Tier 3 Approach

Mineral SOC stocks and stock changes were estimated using the DAYCENT biogeochemical[48] model (Parton et al. 1998; Del Grosso et al. 2001, 2011) as described for *Grassland Remaining Grassland*. The DAYCENT model utilizes the soil C modeling framework developed in the Century model (Parton et al. 1987, 1988, 1994; Metherell et al. 1993), but has been refined to simulate dynamics at a daily time-step. Historical land-use and management patterns were used in the DAYCENT simulations as recorded in the NRI survey (USDA-NCRS 2009), with supplemental information on fertilizer use and rates from the USDA Economic Research Service Cropping Practices Survey (USDA-ERS 1997, 2011) and the National Agricultural Statistics Service (NASS 1992, 1999, 2004). See the *Cropland Remaining Cropland* section for additional discussion of the Tier 3 methodology for mineral soils.

Tier 2 Approach

For the mineral soils not included in the Tier 3 analysis, SOC stock changes were estimated using a Tier 2 Approach for *Land Converted to Grassland* as described in the Tier 2 portion of the *Cropland Remaining Cropland* section for mineral soils.

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Land Converted to Grassland* were estimated using the Tier 2 method provided in IPCC (2006), with U.S.-specific C loss rates (Ogle et al. 2003) as described in the *Cropland Remaining Cropland* section for organic soils.

Uncertainty and Time-Series Consistency

Uncertainty estimates are presented in Table 6-38 for each subsource (i.e., mineral soil C stocks and organic soil C stocks), disaggregated to the level of the inventory methodology employed (i.e., Tier 2 and Tier 3). Uncertainty for the portions of the Inventory estimated with Tier 2 and 3 approaches was derived using a Monte Carlo approach (see Annex 3.12 for further discussion). Uncertainty estimates from each approach were combined using the error propagation equation in accordance with IPCC (2006) (i.e., by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities). The combined uncertainty for soil C stocks in *Land Converted to Grassland* ranged from 107 percent below to 107 percent above the 2013 stock change estimate of -8.8 MMT CO_2 Eq. The large relative uncertainty is due to the small net flux estimate in 2013.

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[47] Federal land is converted into private land in some cases due to changes in ownership. The specific use for federal lands is not identified in the NRI survey (USDA-NRCS 2009), and so the land is assumed to be forest or nominal grassland for purposes of these calculations.

[48] Biogeochemical cycles are the flow of chemical elements and compounds between living organisms and the physical environment.

Table 6-38: Approach 2 Quantitative Uncertainty Estimates for Soil C Stock Changes occurring within *Land Converted to Grassland* (MMT CO_2 Eq. and Percent)

Source	2013 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Cropland Converted to Grassland	**(7.7)**	**(17.1)**	**1.7**	**-122%**	**123%**
Mineral Soil C Stocks: Tier 3	(7.3)	(16.7)	2.0	-127%	127%
Mineral Soil C Stocks: Tier 2	(1.3)	(1.9)	(0.7)	-45%	45%
Organic Soil C Stocks: Tier 2	0.9	0.3	1.8	-63%	98%
Forests Converted to Grassland	**(0.3)**	**(0.6)**	**(0.1)**	**-62%**	**72%**
Mineral Soil C Stocks: Tier 2	(0.4)	(0.6)	(0.2)	-48%	44%
Organic Soil C Stocks: Tier 2	0.1	0.0	0.2	-100%	231%
Other Lands Converted to Grassland	**(0.2)**	**(0.3)**	**(0.1)**	**-48%**	**44%**
Mineral Soil C Stocks: Tier 2	(0.2)	(0.3)	(0.1)	-48%	44%
Organic Soil C Stocks: Tier 2	NA	NA	NA	NA	NA
Settlements Converted to Grassland	**(0.5)**	**(0.7)**	**(0.3)**	**-51%**	**47%**
Mineral Soil C Stocks: Tier 2	(0.5)	(0.8)	(0.3)	-48%	44%
Organic Soil C Stocks: Tier 2	0.0	0.0	0.1	-86%	160%
Wetlands Converted to Grasslands	**(8.5)**	**(17.7)**	**0.7**	**-108%**	**108%**
Mineral Soil C Stocks: Tier 2	(0.1)	(0.2)	(0.1)	-48%	44%
Organic Soil C Stocks: Tier 2	0.1	0.0	0.2	-58%	81%
Total: Land Converted to Grassland	**(8.8)**	**(18.1)**	**0.7**	**-107%**	**107%**
Mineral Soil C Stocks: Tier 3	**(7.3)**	**(16.7)**	**2.0**	**-127%**	**127%**
Mineral Soil C Stocks: Tier 2	**(2.5)**	**(3.2)**	**(1.9)**	**-27%**	**26%**
Organic Soil C Stocks: Tier 2	**1.1**	**0.5**	**2.0**	**-52%**	**81%**

Note: Parentheses indicate negative values.

NA: Other land by definition does not include organic soil (see Section 6.1— of the U.S. Land Base). Consequently, no land areas, C stock changes, or uncertainty results are estimated for land use conversions from Other lands to Croplands and Other lands to Grasslands on organic soils.

[a] Range of flux estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Uncertainty is also associated with lack of reporting of agricultural biomass and litter C stock changes, other than the loss of forest biomass and litter, which is reported in the *Forest Land Remaining Forest Land* section of the report. Biomass C stock changes may be significant for managed grasslands with woody encroachment that has not attained enough tree cover to be considered forest lands. Changes in litter C stocks are assumed to be negligible in grasslands over annual time frames, although there are likely significant changes at sub-annual time scales across seasons.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2013. Details on the emission trends through time are described in more detail in the above Methodology section.

QA/QC and Verification

See the QA/QC and Verification section in *Grassland Remaining Grassland*.

Recalculations Discussion

Methodological recalculations in the current Inventory were associated with the following improvements: 1) refining parameters associated with simulating crop production and carbon inputs to the soil in the DAYCENT biogeochemical model; 2) improving the model simulation of snow melt and water infiltration in soils; and 3) driving the DAYCENT simulations with updated input data for the excretion of C and nitrogen (N) onto Pasture/Range/Paddock and N additions from managed manure based on national livestock population. As a result of these improvements to the Inventory, changes in SOC stocks increased by an average of 0.2 MMT CO_2 eq. annually over the time series.

Planned Improvements

Soil C stock changes with land use conversion from forest land to grassland are undergoing further evaluation to ensure consistency in the time series. Different methods are used to estimate soil C stock changes in forest land and grasslands, and while the areas have been reconciled between these land uses, there has been limited evaluation of the consistency in C stock changes with conversion from forest land to grassland. This planned improvement may not be fully implemented for two more years, depending on resource availability. Another key planned improvement for the *Land Converted to Grassland* category is to develop an inventory of carbon stock changes for the 800,000 to 850,000 hectares of Federal grasslands in the western United States. Grasslands in Alaska will also be evaluated. For information about other improvements, see the Planned Improvements section in *Cropland Remaining Cropland* and *Grassland Remaining Grassland*.

6.8 Wetlands Remaining Wetlands (IPCC Source Category 4D1)

Peatlands Remaining Peatlands

Emissions from Managed Peatlands

Managed peatlands are peatlands which have been cleared and drained for the production of peat. The production cycle of a managed peatland has three phases: land conversion in preparation for peat extraction (e.g., clearing surface biomass, draining), extraction (which results in the emissions reported under *Peatlands Remaining Peatlands*), and abandonment, restoration, or conversion of the land to another use.

CO_2 emissions from the removal of biomass and the decay of drained peat constitute the major GHG flux from managed peatlands. Managed peatlands may also emit CH_4 and N_2O. The natural production of CH_4 is largely reduced but not entirely shut down when peatlands are drained in preparation for peat extraction (Strack et al. 2004 as cited in the *2006 IPCC Guidelines*). Drained land surface and ditch networks contribute to the CH_4 flux in peatlands managed for peat extraction. CH_4 emissions were considered insignificant under IPCC Tier 1 methodology (IPCC 2006), but are included in the emissions estimates for *Peatlands Remaining Peatlands* consistent with the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (IPCC 2013). N_2O emissions from managed peatlands depend on site fertility. In addition, abandoned and restored peatlands continue to release GHG emissions, and at present no methodology is provided by IPCC (2006) to estimate greenhouse gas emissions or removals from restored peatlands; although methodologies are provided for rewetted organic soils (which includes rewetted/restored peatlands) in IPCC (2013) guidelines. This Inventory estimates CO_2, N_2O, and CH_4 emissions from peatlands managed for peat extraction in accordance with IPCC (2006 and 2013) guidelines.

CO_2, N_2O, and CH_4 Emissions from Peatlands Remaining Peatlands

IPCC (2013) recommends reporting CO_2, N_2O, and CH_4 emissions from lands undergoing active peat extraction (i.e., *Peatlands Remaining Peatlands*) as part of the estimate for emissions from managed wetlands. Peatlands occur where plant biomass has sunk to the bottom of water bodies and water-logged areas and exhausted the oxygen supply below the water surface during the course of decay. Due to these anaerobic conditions, much of the plant matter does not decompose but instead forms layers of peat over decades and centuries. In the United States, peat is extracted for horticulture and landscaping growing media, and for a wide variety of industrial, personal care, and other products. It has not been used for fuel in the United States for many decades. Peat is harvested from two types of peat deposits in the United States: sphagnum bogs in northern states (e.g., Minnesota) and wetlands in states further south (e.g., Florida). The peat from sphagnum bogs in northern states, which is nutrient poor, is generally corrected for acidity and mixed with fertilizer. Production from more southerly states is relatively coarse (i.e., fibrous) but nutrient rich.

IPCC (2006 and 2013) recommend considering both on-site and off-site emissions when estimating CO_2 emissions from *Peatlands Remaining Peatlands* using the Tier 1 approach. Current methodologies estimate only on-site N_2O and CH_4 emissions, since off-site N_2O estimates are complicated by the risk of double-counting emissions from nitrogen fertilizers added to horticultural peat, and off-site CH_4 emissions are not relevant given the non-energy uses of peat, so methodologies are not provided in IPCC (2013) guidelines. On-site emissions from managed peatlands occur as the land is cleared of vegetation and the underlying peat is exposed to sun and weather. As this occurs, some peat deposit is lost and CO_2 is emitted from the oxidation of the peat. Since N_2O emissions from saturated ecosystems tend to be low unless there is an exogenous source of nitrogen, N_2O emissions from drained peatlands are dependent on nitrogen mineralization and therefore on soil fertility. Peatlands located on highly fertile soils contain significant amounts of organic nitrogen in inactive form. Draining land in preparation for peat extraction allows bacteria to convert the nitrogen into nitrates which leach to the surface where they are reduced to N_2O, and contributes to the activity of methanogens and methanotrophs (Blodau 2002; Treat et al. 2007 as cited in IPCC 2013). Drainage ditches, which are constructed as land is drained in preparation for peat extraction, also contribute to the flux of CH_4 through *in situ* production and lateral transfer of CH_4 from the organic soil matrix (IPCC 2013).

Off-site CO_2 emissions from managed peatlands occur from waterborne carbon losses and the horticultural and landscaping use of peat. As drainage waters in peatlands accumulate, dissolved organic carbon reacts within aquatic ecosystems and is converted to CO_2, then emitted to the atmosphere (Billet et al. 2004 as cited in IPCC 2013). During the horticultural and landscaping use of peat, nutrient-poor (but fertilizer-enriched) peat tends to be used in bedding plants and in greenhouse and plant nursery production, whereas nutrient-rich (but relatively coarse) peat is used directly in landscaping, athletic fields, golf courses, and plant nurseries. Most (nearly 98 percent) of the CO_2 emissions from peat occur off-site, as the peat is processed and sold to firms which, in the United States, use it predominantly for the aforementioned horticultural and landscaping purposes.

Total emissions from *Peatlands Remaining Peatlands* were estimated to be 0.8 MMT CO_2 Eq. in 2013 (see Table 6-39) comprising 0.8 MMT CO_2 Eq. (770 kt) of CO_2, 0.001 MMT CO_2 Eq. (0.002 kt) of N_2O, and 0.004 MMT CO_2 Eq. (0.16 kt) of CH_4. Total emissions in 2013 were about 5 percent smaller than total emissions in 2012. Peat production in Alaska in 2013 was not reported in *Alaska's Mineral Industry 2013* report. However, peat production reported in the lower 48 states in 2013 was 5 percent lower than in 2012, resulting in smaller total 48 states plus Alaska emissions from *Peatlands Remaining Peatlands* in 2013 compared to 2012.

Total emissions from *Peatlands Remaining Peatlands* have fluctuated between 0.8 and 1.3 MMT CO_2 Eq. across the time series with a decreasing trend from 1990 until 1993 followed by an increasing trend through 2000. After 2000, emissions generally decreased until 2006 and then increased until 2009, when the trend reversed. Emissions in 2013 represent a decline from emissions in 2012. CO_2 emissions from *Peatlands Remaining Peatlands* have fluctuated between 0.8 and 1.3 MMT CO_2 across the time series, and these emissions drive the trends in total emissions. CH_4 and N_2O emissions remained close to zero across the time series. N_2O emissions showed a decreasing trend from 1990 until 1995, followed by an increasing trend through 2001. N_2O emissions decreased between 2001 and 2006, followed by a leveling off between 2008 and 2010, and a decline between 2011 and 2013. CH_4 emissions decreased from 1990 until 1995, followed by an increasing trend through 2000, a period of fluctuation through 2010, then a decline between 2011 and 2013.

Table 6-39: Emissions from *Peatlands Remaining Peatlands* (MMT CO_2 Eq.)

Gas	1990		2005		2009	2010	2011	2012	2013
CO_2	1.1		1.1		1.0	1.0	0.9	0.8	0.8
Off-site	1.0		1.0		1.0	1.0	0.9	0.8	0.7
On-site	0.1		0.1		0.1	0.1	0.1	0.1	+
N_2O (On-site)	+		+		+	+	+	+	+
CH_4 (On-site)	+		+		+	+	+	+	+
Total	**1.1**		**1.1**		**1.0**	**1.0**	**0.9**	**0.8**	**0.8**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
+ Less than 0.05 MMT CO_2 Eq.
Note: These numbers are based on U.S. production data in accordance with Tier 1 guidelines, which does not take into account imports, exports, and stockpiles (i.e., apparent consumption). Off-site N_2O emissions are not estimated to avoid double-counting N_2O emitted from the fertilizer that the peat is mixed with prior to horticultural use (see IPCC 2006). Guidance for estimating off-site CH_4 emissions is not included in IPCC (2013). Totals may not sum due to independent rounding.

Table 6-40: Emissions from *Peatlands Remaining Peatlands* (kt)

Gas	1990	2005	2009	2010	2011	2012	2013
CO_2	1,055	1,101	1,024	1,022	926	812	770
Off-site	985	1,030	957	956	866	760	720
On-site	70	71	67	66	60	53	50
N_2O (On-site)	+	+	+	+	+	+	+
CH_4 (On-site)	+	+	+	+	+	+	+

+ Less than 0.5 kt
Note: These numbers are based on U.S. production data in accordance with Tier 1 guidelines, which does not take into account imports, exports, and stockpiles (i.e., apparent consumption). Off-site N_2O emissions are not estimated to avoid double-counting N_2O emitted from the fertilizer that the peat is mixed with prior to horticultural use (see IPCC 2006). Guidance for estimating off-site CH_4 emissions is not included in IPCC (2013). Totals may not sum due to independent rounding.

Methodology

Off-site CO_2 Emissions

CO_2 emissions from domestic peat production were estimated using a Tier 1 methodology consistent with IPCC (2006). Off-site CO_2 emissions from *Peatlands Remaining Peatlands* were calculated by apportioning the annual weight of peat produced in the United States (Table 6-41) into peat extracted from nutrient-rich deposits and peat extracted from nutrient-poor deposits using annual percentage-by-weight figures. These nutrient-rich and nutrient-poor production values were then multiplied by the appropriate default C fraction conversion factor taken from IPCC (2006) in order to obtain off-site emission estimates. For the lower 48 states, both annual percentages of peat type by weight and domestic peat production data were sourced from estimates and industry statistics provided in the *Minerals Yearbook* and *Mineral Commodity Summaries* from the U.S. Geological Survey (USGS 1995–2014a; USGS 2014b). To develop these data, the U.S. Geological Survey (USGS; U.S. Bureau of Mines prior to 1997) obtained production and use information by surveying domestic peat producers. On average, about 75 percent of the peat operations respond to the survey; and USGS estimates data for non-respondents on the basis of prior-year production levels (Apodaca 2011).

The Alaska estimates rely on reported peat production from the annual *Alaska's Mineral Industry* reports (DGGS 1993–2014). Similar to the U.S. Geological Survey, the Alaska Department of Natural Resources, Division of Geological & Geophysical Surveys (DGGS) solicits voluntary reporting of peat production from producers for the *Alaska's Mineral Industry* report. However, the report does not estimate production for the non-reporting producers, resulting in larger inter-annual variation in reported peat production from Alaska depending on the number of producers who report in a given year (Szumigala 2011). In addition, in both the lower 48 states and Alaska, large variations in peat production can also result from variations in precipitation and the subsequent changes in moisture conditions, since unusually wet years can hamper peat production. The methodology estimates Alaska emissions separately from lower 48 emissions because the state conducts its own mineral survey and reports peat production by volume, rather than by weight (Table 6-42). However, volume production data were used to calculate off-site CO_2 emissions from Alaska applying the same methodology but with volume-specific C fraction conversion factors from IPCC (2006).[49] Peat production was not reported for 2013 in *Alaska's Mineral Industry 2013* report (DGGS 2014); therefore Alaska's peat production in 2013 (reported in cubic yards) was assumed to be equal to its peat production in 2012.

Consistent with IPCC (2013) guidelines, off-site CO_2 emissions from dissolved organic carbon were estimated based on the total area of peatlands managed for peat extraction, which is calculated from production data using the methodology described in the *On-Site CO_2 Emissions* section below. CO_2 emissions from dissolved organic C were

[49] Peat produced from Alaska was assumed to be nutrient poor; as is the case in Canada, "where deposits of high-quality [but nutrient poor] sphagnum moss are extensive" (USGS 2008).

estimated by multiplying the area of peatlands by the default emissions factor for dissolved organic C provided in IPCC (2013).

The *apparent consumption* of peat, which includes production plus imports minus exports plus the decrease in stockpiles, in the United States is over two-and-a-half times the amount of domestic peat production. However, consistent with the Tier 1 method whereby only domestic peat production is accounted for when estimating off-site emissions, off-site CO_2 emissions from the use of peat not produced within the United States are not included in the Inventory. The United States has largely imported peat from Canada for horticultural purposes; from 2010 to 2013, imports of sphagnum moss (nutrient-poor) peat from Canada represented 63 percent of total U.S. peat imports (USGS 2015). Most peat produced in the United States is reed-sedge peat, generally from southern states, which is classified as nutrient rich by IPCC (2006). Higher-tier calculations of CO_2 emissions from apparent consumption would involve consideration of the percentages of peat types stockpiled (nutrient rich versus nutrient poor) as well as the percentages of peat types imported and exported.

Table 6-41: Peat Production of Lower 48 States (kt)

Type of Deposit	1990		2005		2009	2010	2011	2012	2013
Nutrient-Rich	595.1		657.6		560.3	558.9	511.2	409.9	418.5
Nutrient-Poor	55.4		27.4		48.7	69.1	56.8	78.1	46.5
Total Production	**692.0**		**685.0**		**609.0**	**628.0**	**568.0**	**488.0**	**465.0**

Sources: United States Geological Survey (USGS) (1991–2014a) *Minerals Yearbook: Peat (1994–2013);* United States Geological Survey (USGS) (2014b) *Mineral Commodity Summaries: Peat (2013).*

Table 6-42: Peat Production of Alaska (Thousand Cubic Meters)

	1990		2005		2009	2010	2011	2012	2013
Total Production	49.7		47.8		183.9	59.8	61.5	93.1	93.1

Sources: Division of Geological & Geophysical Surveys (DGGS), Alaska Department of Natural Resources (1997–2014) *Alaska's Mineral Industry Report (1997–2013).*

On-site CO_2 Emissions

IPCC (2006) suggests basing the calculation of on-site emission estimates on the area of peatlands managed for peat extraction differentiated by the nutrient type of the deposit (rich versus poor). Information on the area of land managed for peat extraction is currently not available for the United States, but in accordance with IPCC (2006), an average production rate for the industry was applied to derive an area estimate. In a mature industrialized peat industry, such as exists in the United States and Canada, the vacuum method can extract up to 100 metric tons per hectare per year (Cleary et al. 2005 as cited in IPCC 2006).[50] The area of land managed for peat extraction in the United States was estimated using nutrient-rich and nutrient-poor production data and the assumption that 100 metric tons of peat are extracted from a single hectare in a single year. The annual land area estimates were then multiplied by the IPCC (2013) default emission factor in order to calculate on-site CO_2 emission estimates. Production data are not available by weight for Alaska. In order to calculate on-site emissions resulting from *Peatlands Remaining Peatlands* in Alaska, the production data by volume were converted to weight using annual average bulk peat density values, and then converted to land area estimates using the same assumption that a single hectare yields 100 metric tons. The IPCC (2006) on-site emissions equation also includes a term which accounts for emissions resulting from the change in C stocks that occurs during the clearing of vegetation prior to peat extraction. Area data on land undergoing conversion to peatlands for peat extraction is also unavailable for the United States. However, USGS records show that the number of active operations in the United States has been declining since 1990; therefore, it seems reasonable to assume that no new areas are being cleared of vegetation for managed peat

[50] The vacuum method is one type of extraction that annually "mills" or breaks up the surface of the peat into particles, which then dry during the summer months. The air-dried peat particles are then collected by vacuum harvesters and transported from the area to stockpiles (IPCC 2006).

extraction. Other changes in C stocks in living biomass on managed peatlands are also assumed to be zero under the Tier 1 methodology (IPCC 2006 and 2013).

On-site N_2O Emissions

IPCC (2006) suggests basing the calculation of on-site N_2O emission estimates on the area of nutrient-rich peatlands managed for peat extraction. These area data are not available directly for the United States, but the on-site CO_2 emissions methodology above details the calculation of area data from production data. In order to estimate N_2O emissions, the area of nutrient rich *Peatlands Remaining Peatlands* was multiplied by the appropriate default emission factor taken from IPCC (2013).

On-site CH_4 Emissions

IPCC (2013) also suggests basing the calculation of on-site CH_4 emission estimates on the total area of peatlands managed for peat extraction. Area data is derived using the calculation from production data described in the *On-site CO_2* Emissions section above. In order to estimate CH_4 emissions from drained land surface, the area of *Peatlands Remaining Peatlands* was multiplied by the emission factor for direct CH_4 emissions taken from IPCC (2013). In order to estimate CH_4 emissions from drainage ditches, the total area of peatland was multiplied by the default fraction of peatland area that contains drainage ditches, and the appropriate emission factor taken from IPCC (2013).

Uncertainty and Time-Series Consistency

The uncertainty associated with peat production data was estimated to be ± 25 percent (Apodaca 2008) and assumed to be normally distributed. The uncertainty associated with peat production data stems from the fact that the USGS receives data from the smaller peat producers but estimates production from some larger peat distributors. The peat type production percentages were assumed to have the same uncertainty values and distribution as the peat production data (i.e., ± 25 percent with a normal distribution). The uncertainty associated with the reported production data for Alaska was assumed to be the same as for the lower 48 states, or ± 25 percent with a normal distribution. It should be noted that the DGGS estimates that around half of producers do not respond to their survey with peat production data; therefore, the production numbers reported are likely to underestimate Alaska peat production (Szumigala 2008). The uncertainty associated with the average bulk density values was estimated to be ± 25 percent with a normal distribution (Apodaca 2008). IPCC (2006 and 2013) gives uncertainty values for the emissions factors for the area of peat deposits managed for peat extraction based on the range of underlying data used to determine the emission factors. The uncertainty associated with the emission factors was assumed to be triangularly distributed. The uncertainty values surrounding the C fractions were based on IPCC (2006) and the uncertainty was assumed to be uniformly distributed. The uncertainty values associated with the fraction of peatland covered by ditches was assumed to be ± 100 percent with a normal distribution based on the assumption that greater than 10 percent coverage, the upper uncertainty bound, is not typical of drained organic soils outside of The Netherlands (IPCC 2013). Based on these values and distributions, a Monte Carlo (Approach 2) uncertainty analysis was applied to estimate the uncertainty of CO_2, CH_4, and N_2O emissions from *Peatlands Remaining Peatlands*. The results of the Approach 2 quantitative uncertainty analysis are summarized in Table 6-43. CO_2 emissions from *Peatlands Remaining Peatlands* in 2013 were estimated to be between 0.5 and 1.0 MMT CO_2 Eq. at the 95 percent confidence level. This indicates a range of 29 percent below to 32 percent above the 2013 emission estimate of 0.8 MMT CO_2 Eq. N_2O emissions from *Peatlands Remaining Peatlands* in 2013 were estimated to be between 0.0003 and 0.0010 MMT CO_2 Eq. at the 95 percent confidence level. This indicates a range of 55 percent below to 62 percent above the 2013 emission estimate of 0.0006 MMT CO_2 Eq. CH_4 emissions from *Peatlands Remaining Peatlands* in 2013 were estimated to be between 0.002 and 0.007 MMT CO_2 Eq. This indicates a range of 60 percent below to 85 percent above the 2013 emission estimate of 0.004 MMT CO_2 Eq.

Table 6-43: Approach 2 Quantitative Uncertainty Estimates for CO_2, CH_4, and N_2O Emissions from *Peatlands Remaining Peatlands* (MMT CO_2 Eq. and Percent)

Source	Gas	2013 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (MMT CO_2 Eq.)	(%)

			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Peatlands Remaining Peatlands	CO_2	0.8	0.5	1.0	−29%	32%
Peatlands Remaining Peatlands	CH_4	+	+	+	−60%	85%
Peatlands Remaining Peatlands	N_2O	+	+	+	−55%	62%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

+ Does not exceed 0.05 MMT CO_2 eq.

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2013. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

A QA/QC analysis was performed for data gathering and input, documentation, and calculation. The QA/QC analysis revealed an incorrect emission factor for off-site CO_2 emissions from dissolved organic carbon. The emission factor for a boreal climate zone was replaced with the emission factor for a temperate climate zone, which is more representative of the climate zone for the majority of peat producing areas in the United States.

The QA/QC analysis also revealed that revised production estimates for peat were published in the *2013 Minerals Yearbook: Peat* (USGS 2014a). The estimates for the U.S. production of peat and the percentage of sphagnum moss (nutrient-poor peat) reported in the *2013 Mineral Commodity Summaries: Peat* (USGS 2014b) were replaced with the estimates reported in the *2013 Minerals Yearbook: Peat* (USGS 2014a). As a result, the estimate for peat production decreased by 3 percent and the percentage of sphagnum moss decreased by 6 percent.

Recalculations Discussion

The emissions estimates for *Peatlands Remaining Peatlands* were updated to reflect the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (IPCC 2013). IPCC (2013) methodologies include off-site CO_2 emissions from dissolved organic carbon, on-site CH_4 emissions from drainage ditches and drained land surface, and updated emissions factors for off-site CO_2, on-site CO_2, and on-site N_2O emissions estimates. As a result of the methodological changes listed above, CO_2 emissions over the entire time series increased by an average of approximately 1 percent and N_2O emissions over the entire time series decreased by an average of approximately 500 percent. Total emissions from *Peatlands Remaining Peatlands* increased by an average of approximately 1 percent over the entire time series relative to the previous emissions estimates using the IPCC (2006) guidelines.

The current Inventory estimates for 2011 and 2012 were also updated to incorporate information on the volume of peat production in Alaska from *Alaska's Mineral Industry 2012* report (DGGS 2013); and the historical estimate for 2004 was updated to incorporate more recent information on the volume of peat product in Alaska in 2004 from *Alaska's Mineral Industry 2006* report (DGGS 2007). In the previous Inventory report, peat production in Alaska in 2011 and 2012 was assumed to equal the values reported for 2011 and 2012 in the *2012 Minerals Yearbook: Peat* (USGS 2013). As a result of the updated production estimates, emissions decreased by 0.005 percent in 2011, increased by 0.001 percent in 2012, and increased by 10 percent in 2004. Since no peat production was reported in *Alaska's Mineral Industry 2013* report, peat production in Alaska in 2013 was assumed to equal the value reported for 2012 in *Alaska's Mineral Industry 2012* report; this will result in a recalculation in the next Inventory report if the production value is updated.

In addition, for the current Inventory, emission estimates have been revised to reflect the GWPs provided in the *IPCC Fourth Assessment Report* (AR4) (IPCC 2007). AR4 GWP values differ slightly from those presented in the *IPCC Second Assessment Report* (SAR) (IPCC 1996) (used in the previous inventories) which results in time-series recalculations for most inventory sources. Under the most recent reporting guidelines (UNFCCC 2014), countries are required to report using the AR4 GWPs, which reflect an updated understanding of the atmospheric properties of each greenhouse gas. The GWP of CH_4 has increased, leading to an overall increase in CO_2-equivalent emissions from CH_4. The GWP of N_2O has decreased, leading to a decrease in CO_2-equivalent emissions for N_2O. The AR4 GWPs have been applied across the entire time series for consistency. For more information please see the Recalculations and Improvements Chapter. As a result of the updated GWP value for N_2O, N_2O emissions estimates for each year from 1990 to 2012 decreased by 4 percent relative to the N_2O emissions estimates in previous Inventory reports.

Planned Improvements

In order to further improve estimates of CO_2, N_2O, and CH_4 emissions from *Peatlands Remaining Peatlands*, future efforts will consider options for obtaining better data on the quantity of peat harvested per hectare and the total area undergoing peat extraction.

6.9 Settlements Remaining Settlements

Changes in Carbon Stocks in Urban Trees (IPCC Source Category 4E1)

Urban forests constitute a significant portion of the total U.S. tree canopy cover (Dwyer et al. 2000). Urban areas (cities, towns, and villages) are estimated to cover over 3 percent of the United States (U.S. Census Bureau 2012). With an average tree canopy cover of 35 percent, urban areas account for approximately 5 percent of total tree cover in the continental United States (Nowak and Greenfield 2012). Trees in urban areas of the United States were estimated to account for an average annual net sequestration of 75.8 MMT CO_2 Eq. (20.7 MMT C) over the period from 1990 through 2013. Net C flux from urban trees in 2013 was estimated to be −89.5 MMT CO_2 Eq. (−24.4 MMT C). Annual estimates of CO_2 flux (Table 6-44) were developed based on periodic (1990, 2000, and 2010) U.S. Census data on urbanized area. The estimate of urbanized area is smaller than the area categorized as *Settlements* in the Representation of the U.S. Land Base developed for this report, by an average of 48 percent over the 1990 through 2013 time series—i.e., the Census urban area is a subset of the *Settlements* area.

In 2013, urban area was about 44 percent smaller than the total area defined as *Settlements.* Census area data are preferentially used to develop C flux estimates for this source category since these data are more applicable for use with the available peer-reviewed data on urban tree canopy cover and urban tree C sequestration. Annual sequestration increased by 48 percent between 1990 and 2013 due to increases in urban land area. Data on C storage and urban tree coverage were collected since the early 1990s and have been applied to the entire time series in this report. As a result, the estimates presented in this chapter are not truly representative of changes in C stocks in urban trees for *Settlements* areas, but are representative of changes in C stocks in urban trees for Census urban area. The method used in this report does not attempt to scale these estimates to the *Settlements* area. Therefore, the estimates presented in this chapter are likely an underestimate of the true changes in C stocks in urban trees in all *Settlements* areas—i.e., the changes in C stocks in urban trees presented in this chapter are a subset of the changes in C stocks in urban trees in all *Settlements* areas.

Urban trees often grow faster than forest trees because of the relatively open structure of the urban forest (Nowak and Crane 2002). However, areas in each case are accounted for differently. Because urban areas contain less tree coverage than forest areas, the C storage per hectare of land is in fact smaller for urban areas. However, urban tree reporting occurs on a basis of C sequestered per unit area of tree cover, rather than C sequestered per total land area. Expressed per unit of tree cover, areas covered by urban trees have a greater C density than do forested areas (Nowak and Crane 2002). Expressed per unit of land area, however, the situation is the opposite: Urban areas have a smaller C density than forest areas.

Table 6-44: Net C Flux from Urban Trees (MMT CO_2 Eq. and MMT C)

Year	MMT CO_2 Eq.	MMT C
1990	(60.4)	(16.5)
2005	(80.5)	(22.0)
2009	(85.0)	(23.2)
2010	(86.1)	(23.5)

2011	(87.3)	(23.8)
2012	(88.4)	(24.1)
2013	(89.5)	(24.4)

Note: Parentheses indicate net sequestration.

Methodology

Methods for quantifying urban tree biomass, C sequestration, and C emissions from tree mortality and decomposition were taken directly from Nowak et al. (2013), Nowak and Crane (2002), and Nowak (1994). In general, the methodology used by Nowak et al. (2013) to estimate net C sequestration in urban trees followed three steps. First, field data from cities and states were used to generate allometric estimates of biomass from measured tree dimensions. Second, estimates of annual tree growth and biomass increment were generated from published literature and adjusted for tree condition, land-use class, and growing season to generate estimates of gross C sequestration in urban trees for all 50 states and the District of Columbia. Third, estimates of C emissions due to mortality and decomposition were subtracted from gross C sequestration values to derive estimates of net C sequestration. Finally, sequestration estimates for all 50 states and the District of Columbia, in units of C sequestered per unit area of tree cover, were used to estimate urban forest C sequestration in the United States by using urban area estimates from U.S. Census data and urban tree cover percentage estimates for each state and the District of Columbia from remote sensing data, an approach consistent with Nowak et al. (2013).

This approach is also consistent with the default IPCC methodology in IPCC (2006), although sufficient data are not yet available to separately determine interannual gains and losses in C stocks in the living biomass of urban trees.

In order to generate the allometric relationships between tree dimensions and tree biomass for cities and states, Nowak et al. (2013) and previously published research (Nowak and Crane 2002; and Nowak 1994, 2007b, and 2009) collected field measurements in a number of U.S. cities between 1989 and 2012. For a sample of trees in each of the cities in Table 6-45, data including tree measurements of stem diameter, tree height, crown height and crown width, and information on location, species, and canopy condition were collected. The data for each tree were converted into C storage by applying allometric equations to estimate aboveground biomass, a root-to-shoot ratio to convert aboveground biomass estimates to whole tree biomass, moisture content, a C content of 50 percent (dry weight basis), and an adjustment factor of 0.8 to account for urban trees having less aboveground biomass for a given stem diameter than predicted by allometric equations based on forest trees (Nowak 1994). C storage estimates for deciduous trees include only C stored in wood. These calculations were then used to develop an allometric equation relating tree dimensions to C storage for each species of tree, encompassing a range of diameters.

Tree growth was estimated using annual height growth and diameter growth rates for specific land uses and diameter classes. Growth calculations were adjusted by a factor to account for tree condition (fair to excellent, poor, critical, dying, or dead). For each tree, the difference in C storage estimates between year 1 and year (x + 1) represents the gross amount of C sequestered. These annual gross C sequestration rates for each species (or genus), diameter class, and land-use condition (e.g., parks, transportation, vacant, golf courses) were then scaled up to city estimates using tree population information. The area of assessment for each city or state was defined by its political boundaries; parks and other forested urban areas were thus included in sequestration estimates (Nowak 2011).

Most of the field data used to develop the methodology of Nowak et al. (2013) were analyzed using the U.S. Forest Service's Urban Forest Effects (UFORE) model. UFORE is a computer model that uses standardized field data from random plots in each city and local air pollution and meteorological data to quantify urban forest structure, values of the urban forest, and environmental effects, including total C stored and annual C sequestration. UFORE was used with field data from a stratified random sample of plots in each city to quantify the characteristics of the urban forest (Nowak et al. 2007).

Where gross C sequestration accounts for all carbon sequestered, net C sequestration takes into account carbon emissions associated with urban trees. Net C emissions include tree death and removals. Estimates of net C emissions from urban trees were derived by applying estimates of annual mortality and condition, and assumptions about whether dead trees were removed from the site to the total C stock estimate for each city. Estimates of annual mortality rates by diameter class and condition class were derived from a study of street-tree mortality (Nowak 1986). Different decomposition rates were applied to dead trees left standing compared with those removed from the site. For removed trees, different rates were applied to the removed/aboveground biomass in contrast to the belowground biomass. The estimated annual gross C emission rates for each species (or genus), diameter class, and condition class were then scaled up to city estimates using tree population information.

The data for all 50 states and the District of Columbia are described in Nowak et al. (2013), which builds upon previous research, including: Nowak and Crane (2002), Nowak et al. (2007), and references cited therein. The allometric equations applied to the field data for each tree were taken from the scientific literature (see Nowak 1994, Nowak et al. 2002), but if no allometric equation could be found for the particular species, the average result for the genus was used. The adjustment (0.8) to account for less live tree biomass in urban trees was based on information in Nowak (1994). Measured tree growth rates for street (Frelich 1992; Fleming 1988; Nowak 1994), park (deVries 1987), and forest (Smith and Shifley 1984) trees were standardized to an average length of growing season (153 frost free days) and adjusted for site competition and tree condition. Standardized growth rates of trees of the same species or genus were then compared to determine the average difference between standardized street tree growth and standardized park and forest growth rates. Crown light exposure (CLE) measurements (number of sides and/or top of tree exposed to sunlight) were used to represent forest, park, and open (street) tree growth conditions. Local tree base growth rates (BG) were then calculated as the average standardized growth rate for open-grown trees multiplied by the number of frost free days divided by 153. Growth rates were then adjusted for CLE. The CLE adjusted growth rate was then adjusted based on tree health and tree condition to determine the final growth rate. Assumptions for which dead trees would be removed versus left standing were developed specific to each land use and were based on expert judgment of the authors. Decomposition rates were based on literature estimates (Nowak et al. 2013).

Estimates of gross and net sequestration rates for each of the 50 states and the District of Columbia (Table 6-45) were compiled in units of C sequestration per unit area of tree canopy cover. These rates were used in conjunction with estimates of state urban area and urban tree cover data to calculate each state's annual net C sequestration by urban trees. This method was described in Nowak et al. (2013) and has been modified to incorporate U.S. Census data.

Specifically, urban area estimates were based on 1990, 2000, and 2010 U.S. Census data. The 1990 U.S. Census defined urban land as "urbanized areas," which included land with a population density greater than 1,000 people per square mile, and adjacent "urban places," which had predefined political boundaries and a population total greater than 2,500. In 2000, the U.S. Census replaced the "urban places" category with a new category of urban land called an "urban cluster," which included areas with more than 500 people per square mile. In 2010, the Census updated its definitions to have "urban areas" encompassing Census tract delineated cities with 50,000 or more people, and "urban clusters" containing Census tract delineated locations with between 2,500 and 50,000 people. Urban land area increased by approximately 23 percent from 1990 to 2000 and 14 percent from 2000 to 2010; Nowak et al. (2005) estimate that the changes in the definition of urban land are responsible for approximately 20 percent of the total reported increase in urban land area from 1990 to 2000. Under all Census (i.e., 1990, 2000, and 2010) definitions, the urban category encompasses most cities, towns, and villages (i.e., it includes both urban and suburban areas). *Settlements* area, as assessed in the Representation of the U.S. Land Base developed for this report, encompassed all developed parcels greater than 0.1 hectares in size, including rural transportation corridors, and as previously mentioned represents a larger area than the Census-derived urban area estimates. However, the smaller, Census-derived urban area estimates were deemed to be more suitable for estimating national urban tree cover given the data available in the peer-reviewed literature (i.e., the data set available is consistent with Census urban rather than *Settlements* areas), and the recognized overlap in the changes in C stocks between urban forest and non-urban forest (see Planned Improvements below). U.S. Census urban area data is reported as a series of continuous blocks of urban area in each state. The blocks or urban area were summed to create each state's urban area estimate.

Net annual C sequestration estimates were derived for all 50 states and the District of Columbia by multiplying the gross annual emission estimates by 0.74, the standard ratio for net/gross sequestration set out in Table 3 of Nowak et al. (2013) (unless data existed for both gross and net sequestration for the state in Table 2 of Nowak et. al. (2013), in which case they were divided to get a state-specific ratio). The gross and net annual C sequestration values for each state were multiplied by each state's area of tree cover, which was the product of the state's urban/community area as defined in the U.S. Census (2012) and the state's urban/community tree cover percentage. The urban/community tree cover percentage estimates for all 50 states were obtained from Nowak and Greenfield (2012), which compiled ten years of research including Dwyer et al. (2000), Nowak et al. (2002), Nowak (2007a), and Nowak (2009). The urban/community tree cover percentage estimate for the District of Columbia was obtained from Nowak et al.

(2013). The urban area estimates were taken from the 2010 U.S. Census (2012). The equation, used to calculate the summed carbon sequestration amounts, can be written as follows:

$$\text{Net annual C sequestration} = \text{Gross sequestration rate} \times \text{Net to Gross sequestration ratio} \times \text{Urban Area} \times \text{\% Tree Cover}$$

Table 6-45: Annual C Sequestration (Metric Tons C/yr), Tree Cover (Percent), and Annual C Sequestration per Area of Tree Cover (kg C/m²-yr) for 50 states plus the District of Columbia

State	Gross Annual Sequestration	Net Annual Sequestration	Tree Cover	Gross Annual Sequestration per Area of Tree Cover	Net Annual Sequestration per Area of Tree Cover	Net: Gross Annual Sequestration Ratio
Alabama	1,123,944	831,718	55.2	0.343	0.254	0.74
Alaska	44,895	33,223	39.8	0.168	0.124	0.74
Arizona	369,243	273,239	17.6	0.354	0.262	0.74
Arkansas	411,363	304,409	42.3	0.331	0.245	0.74
California	2,092,278	1,548,286	25.1	0.389	0.288	0.74
Colorado	149,005	110,264	18.5	0.197	0.146	0.74
Connecticut	766,512	567,219	67.4	0.239	0.177	0.74
Delaware	129,813	96,062	35.0	0.335	0.248	0.74
DC	14,557	11,568	35.0	0.263	0.209	0.79
Florida	3,331,471	2,465,288	35.5	0.475	0.352	0.74
Georgia	2,476,627	1,832,704	54.1	0.353	0.261	0.74
Hawaii	241,105	178,417	39.9	0.581	0.430	0.74
Idaho	24,658	18,247	10.0	0.184	0.136	0.74
Illinois	747,411	553,084	25.4	0.283	0.209	0.74
Indiana	396,776	366,882	23.7	0.250	0.231	0.92
Iowa	115,796	85,689	19.0	0.240	0.178	0.74
Kansas	182,154	141,747	25.0	0.283	0.220	0.78
Kentucky	237,287	175,592	22.1	0.286	0.212	0.74
Louisiana	727,949	538,683	34.9	0.397	0.294	0.74
Maine	107,875	79,827	52.3	0.221	0.164	0.74
Maryland	586,554	434,050	34.3	0.323	0.239	0.74
Massachusetts	1,294,359	957,826	65.1	0.254	0.188	0.74
Michigan	731,314	541,172	35.0	0.220	0.163	0.74
Minnesota	349,007	258,265	34.0	0.229	0.169	0.74
Mississippi	480,298	355,421	47.3	0.344	0.255	0.74
Missouri	488,287	361,332	31.5	0.285	0.211	0.74
Montana	52,675	38,980	36.3	0.184	0.136	0.74
Nebraska	49,685	41,927	15.0	0.238	0.201	0.84
Nevada	41,797	30,929	9.6	0.207	0.153	0.74
New Hampshire	244,715	181,089	66.0	0.217	0.161	0.74
New Jersey	1,192,996	882,817	53.3	0.294	0.218	0.74
New Mexico	68,789	50,904	12.0	0.263	0.195	0.74
New York	1,090,092	806,668	42.6	0.240	0.178	0.74
North Carolina	1,989,946	1,472,560	51.1	0.312	0.231	0.74
North Dakota	14,372	6,829	13.0	0.223	0.106	0.48
Ohio	910,839	674,021	31.5	0.248	0.184	0.74
Oklahoma	358,363	265,189	31.2	0.332	0.246	0.74
Oregon	257,480	190,535	36.6	0.242	0.179	0.74
Pennsylvania	1,241,922	919,022	41.0	0.244	0.181	0.74
Rhode Island	136,841	101,262	51.0	0.258	0.191	0.74
South Carolina	1,063,705	787,141	48.9	0.338	0.250	0.74
South Dakota	20,356	17,653	14.0	0.236	0.205	0.87
Tennessee	1,030,972	921,810	43.8	0.303	0.271	0.89
Texas	2,712,954	2,007,586	31.4	0.368	0.272	0.74
Utah	87,623	64,841	16.4	0.215	0.159	0.74
Vermont	46,111	34,122	53.0	0.213	0.158	0.74
Virginia	822,286	608,492	39.8	0.293	0.217	0.74
Washington	560,055	414,440	34.6	0.258	0.191	0.74
West Virginia	249,592	184,698	61.0	0.241	0.178	0.74

Wisconsin	356,405	263,739	31.8	0.225	0.167	0.74
Wyoming	18,726	13,857	19.9	0.182	0.135	0.74

Uncertainty and Time-Series Consistency

Uncertainty associated with changes in C stocks in urban trees includes the uncertainty associated with urban area, percent urban tree coverage, and estimates of gross and net C sequestration for each of the 50 states and the District of Columbia. A 10 percent uncertainty was associated with urban area estimates based on expert judgment. Uncertainty associated with estimates of percent urban tree coverage for each of the 50 states was based on standard error estimates reported by Nowak and Greenfield (2012). Uncertainty associated with estimate of percent urban tree coverage for the District of Columbia was based on the standard error estimate reported by Nowak et al. (2013). Uncertainty associated with estimates of gross and net C sequestration for each of the 50 states and the District of Columbia was based on standard error estimates for each of the state-level sequestration estimates reported by Nowak et al. (2013). These estimates are based on field data collected in each of the 50 states and the District of Columbia, and uncertainty in these estimates increases as they are scaled up to the national level.

Additional uncertainty is associated with the biomass equations, conversion factors, and decomposition assumptions used to calculate C sequestration and emission estimates (Nowak et al. 2002). These results also exclude changes in soil C stocks, and there may be some overlap between the urban tree C estimates and the forest tree C estimates. Due to data limitations, urban soil flux is not quantified as part of this analysis, while reconciliation of urban tree and forest tree estimates will be addressed through the land-representation effort described in the Planned Improvements section of this chapter.

A Monte Carlo (Approach 2) uncertainty analysis was applied to estimate the overall uncertainty of the sequestration estimate. The results of the Approach 2 quantitative uncertainty analysis are summarized in Table 6-46. The net C flux from changes in C stocks in urban trees in 2013 was estimated to be between −133.1 and −47.0 MMT CO_2 Eq. at a 95 percent confidence level. This indicates a range of 49 percent more sequestration to 48 percent less sequestration than the 2013 flux estimate of −89.5 MMT CO_2 Eq.

Table 6-46: Approach 2 Quantitative Uncertainty Estimates for Net C Flux from Changes in C Stocks in Urban Trees (MMT CO_2 Eq. and Percent)

Source	Gas	2013 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Changes in C Stocks in Urban Trees	CO_2	(89.5)	(133.1)	(47.0)	49%	−48%

Note: Parentheses indicate negative values or net sequestration.
[a] Range of flux estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2013. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

Tier 1 and Tier 2 QA/QC activities were conducted consistent with the U.S. QA/QC plan. Source-specific quality control measures for urban trees included checking input data, documentation, and calculations to ensure data were properly handled through the inventory process. Errors that were found during this process were corrected as necessary. The net C flux resulting from urban trees was predominately calculated using state-specific estimates of gross and net C sequestration estimates for urban trees and urban tree coverage area published in the literature.

Planned Improvements

A consistent representation of the managed land base in the United States is discussed at the beginning of the *Land Use, Land-Use Change, and Forestry* chapter, and discusses a planned improvement by the USDA Forest Service to reconcile the overlap between urban forest and non-urban forest greenhouse gas inventories. Urban forest inventories are including areas also defined as forest land under the Forest Inventory and Analysis (FIA) program of the USDA Forest Service, resulting in "double-counting" of these land areas in estimates of C stocks and fluxes for this report. For example, Nowak et al. (2013) estimates that 13.7 percent of urban land is measured by the forest inventory plots, and could be responsible for up to 87 MMT C of overlap.

Future research may also enable more complete coverage of changes in the C stock in urban trees for all *Settlements* land. To provide estimates for all *Settlements*, research would need to establish the extent of overlap between *Settlements* and Census-defined urban areas, and would have to characterize sequestration on non-urban *Settlements* land.

N_2O Fluxes from Settlement Soils (IPCC Source Category 4E1)

Of the synthetic N fertilizers applied to soils in the United States, approximately 2.4 percent are currently applied to lawns, golf courses, and other landscaping occurring within settlement areas. Application rates are lower than those occurring on cropped soils, and, therefore, account for a smaller proportion of total U.S. soil N_2O emissions per unit area. In addition to synthetic N fertilizers, a portion of surface applied sewage sludge is applied to settlement areas.

N additions to soils result in direct and indirect N_2O emissions. Direct emissions occur on-site due to the N additions. Indirect emissions result from fertilizer and sludge N that is transformed and transported to another location in a form other than N_2O (NH_3 and NO_x volatilization, NO_3 leaching and runoff), and later converted into N_2O at the off-site location. The indirect emissions are assigned to settlements because the management activity leading to the emissions occurred in settlements.

In 2013, total N_2O emissions from settlement soils were 2.4 MMT CO_2 Eq. (8 kt). There was an overall increase of 77 percent over the period from 1990 through 2013 due to a general increase in the application of synthetic N fertilizers on an expanding settlement area. Interannual variability in these emissions is directly attributable to interannual variability in total synthetic fertilizer consumption and sewage sludge applications in the United States. Emissions from this source are summarized in Table 6-47.

Table 6-47: N_2O Fluxes from Soils in *Settlements Remaining Settlements* (MMT CO_2 Eq. and kt N_2O)

	1990		2005		2009	2010	2011	2012	2013
Direct N_2O Fluxes from Soils									
MMT CO_2 Eq.	1.0		1.8		1.7	1.8	1.9	1.9	1.8
kt N_2O	3		6		6	6	6	6	6
Indirect N_2O Fluxes from Soils									
MMT CO_2 Eq.	0.4		0.6		0.6	0.6	0.6	0.6	0.6
kt N_2O	1		2		2	2	2	2	2
Total									
MMT CO_2 Eq.	**1.4**		**2.3**		**2.2**	**2.4**	**2.5**	**2.5**	**2.4**
kt N_2O	**5**		**8**		**8**	**8**	**8**	**8**	**8**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

Methodology

For soils within *Settlements Remaining Settlements*, the IPCC Tier 1 approach was used to estimate soil N_2O emissions from synthetic N fertilizer and sewage sludge additions. Estimates of direct N_2O emissions from soils in settlements were based on the amount of N in synthetic commercial fertilizers applied to settlement soils, and the amount of N in sewage sludge applied to non-agricultural land and surface disposal (see Annex 3.12 for a detailed discussion of the methodology for estimating sewage sludge application).

Nitrogen applications to settlement soils are estimated using data compiled by the USGS (Ruddy et al. 2006). The USGS estimated on-farm and non-farm fertilizer use is based on sales records at the county level from 1982 through 2001 (Ruddy et al. 2006). Non-farm N fertilizer was assumed to be applied to settlements and forest lands; values for 2002 through 2013 were based on 2001 values adjusted for annual total N fertilizer sales in the United States because there is no new activity data on application after 2001. Settlement application was calculated by subtracting forest application from total non-farm fertilizer use. Sewage sludge applications were derived from national data on sewage sludge generation, disposition, and N content (see Annex 3.12 for further detail). The total amount of N resulting from these sources was multiplied by the IPCC default emission factor for applied N (1 percent) to estimate direct N_2O emissions (IPCC 2006).

For indirect emissions, the total N applied from fertilizer and sludge was multiplied by the IPCC default factors of 10 percent for volatilization and 30 percent for leaching/runoff to calculate the amount of N volatilized and the amount of N leached/runoff. The amount of N volatilized was multiplied by the IPCC default factor of 1 percent for the portion of volatilized N that is converted to N_2O off-site and the amount of N leached/runoff was multiplied by the IPCC default factor of 0.075 percent for the portion of leached/runoff N that is converted to N_2O off-site. The resulting estimates were summed to obtain total indirect emissions.

Uncertainty and Time-Series Consistency

The amount of N_2O emitted from settlements depends not only on N inputs and fertilized area, but also on a large number of variables, including organic C availability, oxygen gas partial pressure, soil moisture content, pH, temperature, and irrigation/watering practices. The effect of the combined interaction of these variables on N_2O flux is complex and highly uncertain. The IPCC default methodology does not explicitly incorporate any of these variables, except variations in fertilizer N and sewage sludge application rates. All settlement soils are treated equivalently under this methodology.

Uncertainties exist in both the fertilizer N and sewage sludge application rates in addition to the emission factors. Uncertainty in fertilizer N application was assigned a default level of ±50 percent.[51] Uncertainty in the amounts of sewage sludge applied to non-agricultural lands and used in surface disposal was derived from variability in several factors, including: (1) N content of sewage sludge; (2) total sludge applied in 2000; (3) wastewater existing flow in 1996 and 2000; and (4) the sewage sludge disposal practice distributions to non-agricultural land application and surface disposal. The uncertainty ranges around 2005 activity data and emission factor input variables were directly applied to the 2013 emission estimates. Uncertainty in the direct and indirect emission factors was provided by the IPCC (2006).

Quantitative uncertainty of this source category was estimated using simple error propagation methods (IPCC 2006). The results of the quantitative uncertainty analysis are summarized in Table 6-48. Direct N_2O emissions from soils in *Settlements Remaining Settlements* in 2013 were estimated to be between 0.9 and 4.8 MMT CO_2 Eq. at a 95 percent confidence level. This indicates a range of 49 percent below to 163 percent above the 2013 emission estimate of 1.8 MMT CO_2 Eq. Indirect N_2O emissions in 2013 were between 0.1 and 1.9 MMT CO_2 Eq., ranging from a -85 percent to 212 percent around the estimate of 0.6 MMT CO_2 Eq.

Table 6-48: Quantitative Uncertainty Estimates of N_2O Emissions from Soils in *Settlements Remaining Settlements* (MMT CO_2 Eq. and Percent)

Source	Gas	2013 Emissions (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate (MMT CO_2 Eq.)		(%)	
Settlements Remaining Settlements:			**Lower Bound**	**Upper Bound**	**Lower Bound**	**Upper Bound**
Direct N_2O Fluxes from Soils	N_2O	1.8	0.9	4.8	-49%	163%
Indirect N_2O Fluxes from Soils	N_2O	0.6	0.1	1.9	-85%	212%

Note: These estimates include direct and indirect N_2O emissions from N fertilizer additions to both *Settlements Remaining Settlements* and from *Land Converted to Settlements*.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2013. Details on the emission trends through time are described in more detail in the Methodology section, above.

[51] No uncertainty is provided with the USGS fertilizer consumption data (Ruddy et al. 2006) so a conservative ±50 percent was used in the analysis.

QA/QC and Verification

The spreadsheet containing fertilizer and sewage sludge applied to settlements and calculations for N_2O and uncertainty ranges were checked and corrections were made. Linkage errors in the uncertainty calculation for 2013 were found and corrected. The reported emissions in the Inventory were also adjusted accordingly.

Recalculations Discussion

Indirect emissions from settlements were previously reported in *Agricultural Soil Management*, but are now included in this source category. Including indirect emissions resulted in a 66 percent increase.

For the current Inventory, emission estimates have been revised to reflect the GWPs provided in the *IPCC Fourth Assessment Report* (AR4) (IPCC 2007). AR4 GWP values differ slightly from those presented in the *IPCC Second Assessment Report* (SAR) (IPCC 1996) (used in the previous Inventories) which results in time-series recalculations for most Inventory sources. Under the most recent reporting guidelines (UNFCCC 2014), countries are required to report using the AR4 GWPs, which reflect an updated understanding of the atmospheric properties of each greenhouse gas. The GWP of N_2O decreased, leading to a decrease in CO_2-equivalent emissions for N_2O. The AR4 GWPs have been applied across the entire time series for consistency. For more information please see the Recalculations and Improvements Chapter.

Planned Improvements

A minor improvement is planned to update the uncertainty analysis for direct emissions from settlements to be consistent with the most recent activity data for this source.

6.10 Land Converted to Settlements (IPCC Source Category 4E2)

Land-use change is constantly occurring, and land under a number of uses undergoes urbanization in the United States each year. However, data on the amount of land converted to settlements is currently lacking. Given the lack of available information relevant to this particular IPCC source category, it is not possible to separate CO_2 or N_2O fluxes on *Land Converted to Settlements* from fluxes on *Settlements Remaining Settlements* at this time.

6.11 Other (IPCC Source Category 4H)

Changes in Yard Trimming and Food Scrap Carbon Stocks in Landfills

In the United States, yard trimmings (i.e., grass clippings, leaves, and branches) and food scraps account for a significant portion of the municipal waste stream, and a large fraction of the collected yard trimmings and food scraps are discarded in landfills. Carbon (C) contained in landfilled yard trimmings and food scraps can be stored for very long periods.

Carbon-storage estimates are associated with particular land uses. For example, harvested wood products are accounted for under *Forest Land Remaining Forest Land* because these wood products are considered a component of the forest ecosystem. The wood products serve as reservoirs to which C resulting from photosynthesis in trees is transferred, but the removals in this case occur in the forest. Carbon stock changes in yard trimmings and food scraps are associated with settlements, but removals in this case do not occur within settlements. To address this complexity, yard trimming and food scrap C storage is reported under the "Other" source category.

Both the amount of yard trimmings collected annually and the fraction that is landfilled have declined over the last decade. In 1990, over 53 million metric tons (wet weight) of yard trimmings and food scraps were generated (i.e., put at the curb for collection to be taken to disposal sites or to composting facilities) (EPA 2014a). Since then, programs banning or discouraging yard trimmings disposal have led to an increase in backyard composting and the use of mulching mowers, and a consequent 3 percent decrease in the tonnage of yard trimmings generated (i.e., collected for composting or disposal). At the same time, an increase in the number of municipal composting facilities has reduced the proportion of collected yard trimmings that are discarded in landfills—from 72 percent in 1990 to 35 percent in 2013. The net effect of the reduction in generation and the increase in composting is a 53 percent decrease in the quantity of yard trimmings disposed of in landfills since 1990.

Food scrap generation has grown by 53 percent since 1990, and though the proportion of food scraps discarded in landfills has decreased slightly from 82 percent in 1990 to 78 percent in 2013, the tonnage disposed of in landfills has increased considerably (by 46 percent). Overall, the decrease in the landfill disposal rate of yard trimmings has more than compensated for the increase in food scrap disposal in landfills, and the net result is a decrease in annual landfill C storage from 26.0 MMT CO_2 Eq. (7.1 MMT C) in 1990 to 12.6 MMT CO_2 Eq. (3.4 MMT C) in 2013 (Table 6-49 and Table 6-50).

Table 6-49: Net Changes in Yard Trimming and Food Scrap Carbon Stocks in Landfills (MMT CO_2 Eq.)

Carbon Pool	1990		2005		2009	2010	2011	2012	2013
Yard Trimmings	(21.0)		(7.4)		(8.5)	(9.3)	(9.4)	(9.3)	(9.3)
Grass	(1.8)		(0.6)		(0.8)	(0.9)	(0.9)	(0.9)	(0.9)
Leaves	(9.0)		(3.4)		(3.9)	(4.2)	(4.3)	(4.3)	(4.3)
Branches	(10.2)		(3.4)		(3.8)	(4.1)	(4.2)	(4.2)	(4.2)
Food Scraps	(5.0)		(4.0)		(4.0)	(3.9)	(3.8)	(3.4)	(3.3)
Total Net Flux	**(26.0)**		**(11.4)**		**(12.5)**	**(13.2)**	**(13.2)**	**(12.8)**	**(12.6)**

Note: Parentheses indicate net sequestration.

Table 6-50: Net Changes in Yard Trimming and Food Scrap Carbon Stocks in Landfills (MMT C)

Carbon Pool	1990		2005		2009	2010	2011	2012	2013
Yard Trimmings	**(5.7)**		**(2.0)**		**(2.3)**	**(2.5)**	**(2.6)**	**(2.5)**	**(2.5)**
Grass	(0.5)		(0.2)		(0.2)	(0.3)	(0.3)	(0.2)	(0.2)
Leaves	(2.5)		(0.9)		(1.1)	(1.1)	(1.2)	(1.2)	(1.2)
Branches	(2.8)		(0.9)		(1.0)	(1.1)	(1.1)	(1.1)	(1.1)
Food Scraps	**(1.4)**		**(1.1)**		**(1.1)**	**(1.1)**	**(1.0)**	**(0.9)**	**(0.9)**
Total Net Flux	**(7.1)**		**(3.1)**		**(3.4)**	**(3.6)**	**(3.6)**	**(3.5)**	**(3.4)**

Note: Parentheses indicate net sequestration.

Methodology

When wastes of biogenic origin (such as yard trimmings and food scraps) are landfilled and do not completely decompose, the C that remains is effectively removed from the global C cycle. Empirical evidence indicates that yard trimmings and food scraps do not completely decompose in landfills (Barlaz 1998, 2005, 2008; De la Cruz and Barlaz 2010), and thus the stock of C in landfills can increase, with the net effect being a net atmospheric removal of C. Estimates of net C flux resulting from landfilled yard trimmings and food scraps were developed by estimating the change in landfilled C stocks between inventory years, based on methodologies presented for the *Land Use, Land-Use Change, and Forestry* sector in IPCC (2003). Carbon stock estimates were calculated by determining the mass of landfilled C resulting from yard trimmings or food scraps discarded in a given year; adding the accumulated landfilled C from previous years; and subtracting the mass of C that was landfilled in previous years that decomposed.

To determine the total landfilled C stocks for a given year, the following were estimated: (1) The composition of the yard trimmings; (2) the mass of yard trimmings and food scraps discarded in landfills; (3) the C storage factor of the landfilled yard trimmings and food scraps; and (4) the rate of decomposition of the degradable C. The composition of yard trimmings was assumed to be 30 percent grass clippings, 40 percent leaves, and 30 percent branches on a wet weight basis (Oshins and Block 2000). The yard trimmings were subdivided, because each component has its own unique adjusted C storage factor (i.e., moisture content and C content) and rate of decomposition. The mass of yard trimmings and food scraps disposed of in landfills was estimated by multiplying the quantity of yard trimmings and food scraps discarded by the proportion of discards managed in landfills. Data on discards (i.e., the amount generated minus the amount diverted to centralized composting facilities) for both yard trimmings and food scraps were taken primarily from *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: 2012 Facts and Figures* (EPA 2014a), which provides data for 1960, 1970, 1980, 1990, 2000, 2005, 2008 and 2010 through 2012. To provide data for some of the missing years, detailed backup data were obtained from historical data tables that EPA developed for 1960 through 2012 (EPA 2014b). Remaining years in the time series for which data were not provided were estimated using linear interpolation. Data for 2013 are not yet available, so they were set equal to 2012 values. The EPA (2014a) report and historical data tables (EPA 2014b) do not subdivide the discards (i.e., total generated minus composted) of individual materials into masses landfilled and combusted, although it provides a mass of overall waste stream discards managed in landfills[52] and combustors with energy recovery (i.e., ranging from 67 percent and 33 percent, respectively, in 1960 to 92 percent and 8 percent, respectively, in 1985); it is assumed that the proportion of each individual material (food scraps, grass, leaves, branches) that is landfilled is the same as the proportion across the overall waste stream.

The amount of C disposed of in landfills each year, starting in 1960, was estimated by converting the discarded landfilled yard trimmings and food scraps from a wet weight to a dry weight basis, and then multiplying by the initial (i.e., pre-decomposition) C content (as a fraction of dry weight). The dry weight of landfilled material was calculated using dry weight to wet weight ratios (Tchobanoglous et al. 1993, cited by Barlaz 1998) and the initial C contents and the C storage factors were determined by Barlaz (1998, 2005, 2008) (Table 6-51).

The amount of C remaining in the landfill for each subsequent year was tracked based on a simple model of C fate. As demonstrated by Barlaz (1998, 2005, 2008), a portion of the initial C resists decomposition and is essentially persistent in the landfill environment. Barlaz (1998, 2005, 2008) conducted a series of experiments designed to measure biodegradation of yard trimmings, food scraps, and other materials, in conditions designed to promote decomposition (i.e., by providing ample moisture and nutrients). After measuring the initial C content, the materials were placed in sealed containers along with methanogenic microbes from a landfill. Once decomposition was complete, the yard trimmings and food scraps were re-analyzed for C content; the C remaining in the solid sample can be expressed as a proportion of initial C (shown in the row labeled "C Storage Factor, Proportion of Initial C Stored (%)" in Table 6-51).

The modeling approach applied to simulate U.S. landfill C flows builds on the findings of Barlaz (1998, 2005, 2008). The proportion of C stored is assumed to persist in landfills. The remaining portion is assumed to degrade over time, resulting in emissions of CH_4 and CO_2. (The CH_4 emissions resulting from decomposition of yard trimmings and food scraps are accounted for in the *Waste* chapter.) The degradable portion of the C is assumed to decay according to first-order kinetics. The decay rates for each of the materials are shown in Table 6-51.

The first-order decay rates, *k*, for each component were derived from De la Cruz and Barlaz (2010). De la Cruz and Barlaz (2010) calculate first-order decay rates using laboratory data published in Eleazer et al. (1997), and a correction factor, *f*, is found so that the weighted average decay rate for all components is equal to the AP-42 default decay rate (0.04) for mixed MSW for regions that receive more than 25 inches of rain annually. Because AP-42 values were developed using landfill data from approximately 1990, 1990 waste composition for the United States from EPA's *Characterization of Municipal Solid Waste in the United States: 1990 Update* was used to calculate *f*. This correction factor is then multiplied by the Eleazer et al. (1997) decay rates of each waste component to develop field-scale first-order decay rates.

[52] EPA (2014) reports discards in two categories: "combustion with energy recovery" and "landfill, other disposal," which includes combustion without energy recovery. For years in which there is data from previous EPA reports on combustion without energy recovery, EPA assumes these estimates are still applicable. For 2000 to present, EPA assumes that any combustion of MSW that occurs includes energy recovery, so all discards to "landfill, other disposal" are assumed to go to landfills.

De la Cruz and Barlaz (2010) also use other assumed initial decay rates for mixed MSW in place of the AP-42 default value based on different types of environments in which landfills in the United States are found, including dry conditions (less than 25 inches of rain annually, k=0.02) and bioreactor landfill conditions (moisture is controlled for rapid decomposition, k=0.12). The *Landfills* section of the Inventory (which estimates CH_4 emissions) estimates the overall MSW decay rate by partitioning the U.S. landfill population into three categories, based on annual precipitation ranges of: (1) Less than 20 inches of rain per year, (2) 20 to 40 inches of rain per year, and (3) greater than 40 inches of rain per year. These correspond to overall MSW decay rates of 0.020, 0.038, and 0.057 $year^{-1}$, respectively.

De la Cruz and Barlaz (2010) calculate component-specific decay rates corresponding to the first value (0.020 $year^{-1}$), but not for the other two overall MSW decay rates. To maintain consistency between landfill methodologies across the Inventory, the correction factors (f) were developed for decay rates of 0.038 and 0.057 $year^{-1}$ through linear interpolation. A weighted national average component-specific decay rate was calculated by assuming that waste generation is proportional to population (the same assumption used in the landfill methane emission estimate), based on population data from the 2000 U.S. Census. The component-specific decay rates are shown in Table 6-51.

For each of the four materials (grass, leaves, branches, food scraps), the stock of C in landfills for any given year is calculated according to the following formula:

$$LFC_{i,t} = \sum_{n}^{t} W_{i,n} \times (1 - MC_i) \times ICC_i \times \{[CS_i \times ICC_i] + [(1 - (CS_i \times ICC_i)) \times e^{-k(t-n)}]\}$$

where,

t	=	Year for which C stocks are being estimated (year),
i	=	Waste type for which C stocks are being estimated (grass, leaves, branches, food scraps),
$LFC_{i,t}$	=	Stock of C in landfills in year t, for waste i (metric tons),
$W_{i,n}$	=	Mass of waste i disposed of in landfills in year n (metric tons, wet weight),
n	=	Year in which the waste was disposed of (year, where 1960 < n < t),
MC_i	=	Moisture content of waste i (percent of water),
CS_i	=	Proportion of initial C that is stored for waste i (percent),
ICC_i	=	Initial C content of waste i (percent),
e	=	Natural logarithm, and
k	=	First-order decay rate for waste i, ($year^{-1}$).

For a given year t, the total stock of C in landfills ($TLFC_t$) is the sum of stocks across all four materials (grass, leaves, branches, food scraps). The annual flux of C in landfills (F_t) for year t is calculated as the change in stock compared to the preceding year:

$$F_t = TLFC_t - TLFC_{(t-1)}$$

Thus, the C placed in a landfill in year n is tracked for each year t through the end of the inventory period (2013). For example, disposal of food scraps in 1960 resulted in depositing about 1,135,000 metric tons of C. Of this amount, 16 percent (179,000 metric tons) is persistent; the remaining 84 percent (956,000 metric tons) is degradable. By 1965, more than half of the degradable portion (518,000 metric tons) decomposes, leaving a total of 617,000 metric tons (the persistent portion, plus the remainder of the degradable portion).

Continuing the example, by 2013, the total food scraps C originally disposed of in 1960 had declined to 179,000 metric tons (i.e., virtually all degradable C had decomposed). By summing the C remaining from 1960 with the C remaining from food scraps disposed of in subsequent years (1961 through 2013), the total landfill C from food scraps in 2013 was 40.8 million metric tons. This value is then added to the C stock from grass, leaves, and branches to calculate the total landfill C stock in 2013, yielding a value of 262.0 million metric tons (as shown in Table 6-52). In exactly the same way total net flux is calculated for forest C and harvested wood products, the total net flux of landfill C for yard trimmings and food scraps for a given year (Table 6-50) is the difference in the landfill C stock for that year and the stock in the preceding year. For example, the net change in 2013 shown in Table 6-50 (3.4 MMT C) is equal to the stock in 2013 (262.1 MMT C) minus the stock in 2012 (258.6 MMT C).

The C stocks calculated through this procedure are shown in Table 6-52.

Table 6-51: Moisture Contents, C Storage Factors (Proportions of Initial C Sequestered), Initial C Contents, and Decay Rates for Yard Trimmings and Food Scraps in Landfills

Variable	Yard Trimmings			Food Scraps
	Grass	Leaves	Branches	
Moisture Content (% H_2O)	70	30	10	70
C Storage Factor, Proportion of Initial C Stored (%)	53	85	77	16
Initial C Content (%)	45	46	49	51
Decay Rate ($year^{-1}$)	0.323	0.185	0.016	0.156

Table 6-52: C Stocks in Yard Trimmings and Food Scraps in Landfills (MMT C)

Carbon Pool	1990	2005	2009	2010	2011	2012	2013
Yard Trimmings	**155.8**	**202.9**	**211.0**	**213.6**	**216.1**	**218.7**	**221.2**
Branches	14.5	18.1	18.8	19.0	19.3	19.5	19.8
Leaves	66.7	87.3	91.1	92.2	93.4	94.5	95.7
Grass	74.6	97.5	101.2	102.3	103.5	104.6	105.7
Food Scraps	**17.6**	**32.8**	**36.9**	**38.0**	**39.0**	**39.9**	**40.8**
Total Carbon Stocks	**173.5**	**235.6**	**248.0**	**251.6**	**255.1**	**258.6**	**262.1**

Uncertainty and Time-Series Consistency

The uncertainty analysis for landfilled yard trimmings and food scraps includes an evaluation of the effects of uncertainty for the following data and factors: disposal in landfills per year (tons of C), initial C content, moisture content, decay rate, and proportion of C stored. The C storage landfill estimates are also a function of the composition of the yard trimmings (i.e., the proportions of grass, leaves and branches in the yard trimmings mixture). There are respective uncertainties associated with each of these factors.

A Monte Carlo (Approach 2) uncertainty analysis was applied to estimate the overall uncertainty of the sequestration estimate. The results of the Approach 2 quantitative uncertainty analysis are summarized in Table 6-53. Total yard trimmings and food scraps CO_2 flux in 2013 was estimated to be between -19.3 and -4.9 MMT CO_2 Eq. at a 95 percent confidence level (or 19 of 20 Monte Carlo stochastic simulations). This indicates a range of 53 percent below to 61 percent above the 2013 flux estimate of -12.6 MMT CO_2 Eq. More information on the uncertainty estimates for Yard Trimmings and Food Scraps in Landfills is contained within the Uncertainty Annex.

Table 6-53: Approach 2 Quantitative Uncertainty Estimates for CO_2 Flux from Yard Trimmings and Food Scraps in Landfills (MMT CO_2 Eq. and Percent)

Source	Gas	2013 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Yard Trimmings and Food Scraps	CO_2	(12.6)	(19.3)	(4.9)	-53%	+61%

[a] Range of flux estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
Note: Parentheses indicate negative values or net C sequestration.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2013. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

A QA/QC analysis was performed for data gathering and input, documentation, and calculation. The QA/QC analysis did not reveal any inaccuracies or incorrect input values.

Recalculations Discussion

The current Inventory has been revised relative to the previous report. Generation and recovery data for yard trimmings and food scraps was not previously provided for every year from 1960 in the *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures* report. EPA has since released historical data, which included data for each year from 1960 through 2012. The recalculations based on these historical data resulted in changes ranging from a 17 percent increase in sequestration in 1996 to a 5 percent decrease in sequestration in 2005, and an average 4 percent increase in sequestration across the 1990–2012 time series compared to the previous Inventory.

Planned Improvements

Future work is planned to evaluate the consistency between the estimates of C storage described in this chapter and the estimates of landfill CH_4 emissions described in the *Waste* chapter. For example, the *Waste* chapter does not distinguish landfill CH_4 emissions from yard trimmings and food scraps separately from landfill CH_4 emissions from total bulk (i.e., municipal solid) waste, which includes yard trimmings and food scraps.